NAVPERS 10539

ENGINEMAN 3

NAVY TRAINING COURSES

ENGINEMAN 3

Prepared by
BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES
NavPers 10539

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

PREFACE

This training course has been prepared to serve as an aid to enlisted men of the regular Navy and the Naval Reserve who are preparing for advancement to the rate of Engineman 3. When supplemented by the necessary practical experience and a thorough knowledge of the material in the applicable Basic Navy Training Courses, a knowledge of the material in this training course will enable you to meet the requirements for advancement.

Engineman 3 is a new training course, and contains information related to the current qualifications for advancement. The qualifications for the Engineman rating, as given in *The Manual of Qualifications for Advancement in Rating*, NavPers 18068, Revised, are listed in appendix II of this training course. Since the examinations for advancement are based upon these qualifications, it is suggested that you refer to them frequently for guidance as you study this course.

The first chapter of this training course contains information concerning the general scope of the Engineman rating and the duties and responsibilities of the Engineman 3. Sources of additional information and helpful hints on how to use this course are also provided in chapter 1. The remainder of this training course deals principally with the internal combustion engines used by the Navy; however, other machinery for which Enginemen are responsible is also discussed. Emphasis is placed on operation and maintenance factors of which the Engineman 3 must have a thorough knowledge.

As one of the NAVY TRAINING COURSES, *Engineman 3* has been prepared by the U. S. Navy Training Publications Center for the Bureau of Naval Personnel. Technical assistance has been furnished by the Bureau of Ships and by the U. S. Naval Schools, Enginemen, U. S. Naval Training Center, Great Lakes.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E-2 or 8 mos. total service.	6 mos. as E-3 or 14 mos. total service.	12 mos. as E-4.	12 mos. as E-5; total service at least 36 mos.	36 mos. as E-6.
SCHOOL	Recruit Training.		Class A for PR3, PRS3.		Class B for MN1.	Class B for AGCA, MNCA, MUCA.
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.			
PRACTICAL FACTORS	Locally prepared check-offs.		Records of Practical Factors, NavPers 760, must be completed for all PO advancements.			
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.			
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.			
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.				
AUTHORIZATION	Commanding Officer		U. S. Naval Examining Center			BuPers
	TARS are advanced to fill vacancies and must be approved by district commandants or CNARESTRA.					

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48 12 NON-DRILLING	9 mos. 9 mos. 12 mos.	9 mos. 15 mos. 24 mos.	15 mos. 21 mos. 24 mos.	18 mos. 24 mos. 36 mos.	24 mos. 36 mos. 48 mos.	36 mos. 42 mos. 48 mos.
DRILLS ATTENDED IN GRADE#	48 24 12	27 16 8	27 16 13	45 27 18	54 32 20	72 42 32	108 64 38
TOTAL TRAINING DUTY IN GRADE#	24 OR 48 12 NON-DRILLING	14 days 14 days None	14 days 14 days None	14 days 14 days 14 days	14 days 28 days 14 days	28 days 42 days 28 days	42 days 42 days 28 days
PERFORMANCE TESTS				Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316, must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

#Active duty periods may be substituted for drills and training duty.

READING LIST

NAVY TRAINING COURSES

Basic Hand Tool Skills (metal working skills only)	NavPers 10085
Fundamentals of Diesel Engines (Chapters 1 & 2)	NavPers 16178–A
General Training Course for Petty Officers	NavPers 10055

OTHER PUBLICATIONS

BuShips Manual (Chaps. 45, 58)

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for supplementary reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

CORRESPONDENCE

Number	Title
CB 794	*Principles of Diesel Engines*
CA 795	*Diesel Engine Maintenance & Repair*
CC 936	*Refrigeration*

SELF-TEACHING

MB 794	*Principles Of Diesel Engines*
MC 936	*Refrigeration*

* "Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, service, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active-duty orders."

CREDITS

All illustrations published in *Engineman 3* are official U. S. Navy illustrations, unless designated below.

Source	*Figures*
American Bosch Corporation, Springfield, Mass.	15–2.
Boeing Airplane Co., Seattle, Washington	2–13, 2–14, 2–15, 2–16, 2–17.
Chrysler Corporation, Detroit, Mich.	4–4, 6–22, 8–3, 10–14, 10–15, 11–1, 15–3.
Cooper-Bessemer Corporation, Mt. Vernon, Ohio	3–2, 3–8, 3–15, 4–2, 4–8, 4–18, 5–13, 5–14, 5–17, 5–20, 6–14, 6–15, 6–16, 6–17, 6–18, 7–5, 7–6, 10–2, 10–6, 10–8, 11–7, 11–8, 11–17, 12–4.
DeLaval Separator Co., New York, N. Y.	9–1, 9–2, 9–3, 9–4, 9–5.
Electric Auto-Lite Co., Toledo, Ohio	8–1.
Ex-Cell-O Corp., Detroit, Mich.	15–1.
Fairbanks, Morse & Co., Chicago, Ill.	2–9, 3–16, 4–9, 6–10, 6–11, 6–12, 6–13, 7–4, 10–9, 10–12, 11–20.
General Motors Corporation	
Cleveland Diesel Engine Division, Cleveland, Ohio	3–11, 3–12, 3–17, 3–22B, 3–23, 4–19A; 4–22, 5–8, 5–9, 5–10, 5–19, 6–5, 6–6, 6–7, 6–8, 10–1, 10–3, 10–4, 10–5, 10–7, 10–10, 10–11, 10–17, 11–15, 11–19, 12–7, 12–8, 15–4.
Delco-Remy Division, Anderson, Indiana	8–2, 8–4, 8–5, 8–6, 8–7, 8–8, 8–9.
Detroit Diesel Engine Division, Detroit, Mich.	3–1, 3–9, 3–10, 3–19, 3–22A, 4–17, 5–1, 5–4, 5–5, 5–7, 5–16, 6–1, 6–2, 6–3, 6–4, 10–18, 11–14, 12–5, 13–1.
Electro-Motive Division, LaGrange, Illinois	3–24, 4–13, 10–13.
Harrison Radiator Division, Lockport, N. Y.	11–9, 11–10, 11–11, 11–12, 11–13.
Gray Marine Motor Co., Detroit, Mich.	2–2, 2–3, 11–3, 11–6, 11–18, 14–3.
Griscom-Russel Co., Massillon, Ohio	19–2, 19–4.
Johnson Motors, Waukegan, Ill.	4–3, 4–11, 8–13, 10–16, 12–6.
Packard Motor Car Company, Detroit, Mich.	5–6, 5–15, 5–18, 7–1, 11–4, 11–5.

STUDY GUIDE

The table below indicates the chapters of this book which you should study. To use it, select the column which applies to the rating for which you are striking. If you are advancing in the General Service Rating, every chapter of this book applies. If you are in the Reserve or are advancing in an emergency service rating for some other reason, use the column headed by your particular Emergency Service Rating, either END (Diesel Engineman) or ENG (Gasoline Engineman).

It is well for a man in any of the emergency service ratings to have an idea of the duties of the general service rating. Consequently, although a chapter may not apply to your particular duties, it will do you no harm to read it. But you must make a close study of designated chapters because they apply to qualifications which you must meet for advancement. These qualifications are listed in appendix II. The answers to the quizzes at the end of the chapters are given in appendix I.

Chapter	EN	END	ENG
1	x	x	x
2	x	Part	Part
3	x	x	x
4	x	x	x
5	x	Part	Part
6	x	Part	Part
7	x	Part	Part
8	x	Part	Part
9	x	x	x
10	x	Part	Part
11	x	x	x
12	x	x	x
13	x	Part	Part
14	x	x	x
15	x	x	x
16	x	Part	Part
17	x	x	x
18	x	x	Part
19	x	x	x

Note: Where the word Part appears it means that part of the chapter concerns diesel engines and part concerns gasoline engines. END's and ENG's should study appropriate parts of these chapters.

CONTENTS

Section II

SHIPBOARD AUXILIARY MACHINERY AND EQUIPMENT

ENGINEMAN 3

CHAPTER 1

THE ENGINEMAN

As a Fireman, you have proved that you can perform many of the duties required of Navy enlisted men. You have established the fact that you are capable of standing messenger, cold iron, and fire watches; of locating and identifying engineering equipment; and of making minor repairs to engineering equipment. You have learned the functions of many of the auxiliary machines found aboard ship. You have passed the test as a boat engineer. You have learned a great deal about the military responsibilities you share with your shipmates. Having proved your capabilities, you have been designated as an Engineman striker. You have now arrived at one of the most important points in your naval career, the point where you begin to assume responsibilities within an occupational group in the Navy.

ADVANCEMENT

The training mission of the peacetime Navy is to produce broadly qualified, versatile personnel who, in time of emergency, can be advanced to positions of greater responsibility and authority. There are many jobs to be done if this mission is to be accomplished. These jobs have been classified into 12 occupational groups which are identified as Navy enlisted men's ratings. These ratings are frequently displayed in poster form under the head-

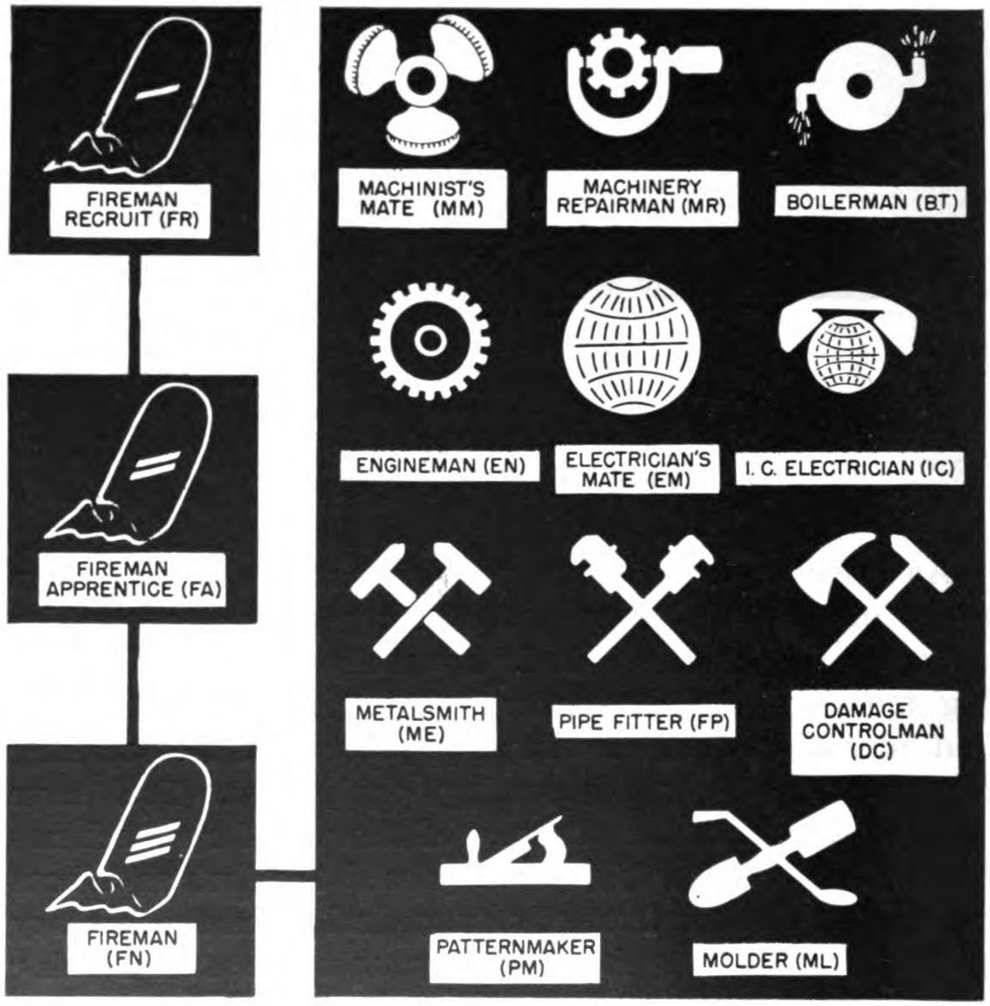


Figure 1—1.—Paths of Advancement.

ing, Paths of Advancement of Enlisted Personnel in the United States Navy. See figure 1–1 which shows that portion of this poster which deals with the Engineering and Hull ratings.

Ratings

An occupational group of jobs requiring similar interests, abilities, training, experience, knowledge, and skills is called a rating. A rating identifies a Navy occupation. Not all men within a rating do exactly the same job, but all men in the same rating need many skills and knowledges in common.

GENERAL SERVICE.—In peacetime, the degree of specialization of duties within a rating is limited by the authorized manpower strength; therefore, each job assignment requires the performance of many different but related functions. For this reason, the ratings earned by petty officers in the peacetime regular Navy are termed general service ratings. A general service Engineman is held responsible for all types of engines and related equipment.

EMERGENCY SERVICE.—Under mobilization conditions, when the active-duty ranks of the Navy are greatly expanded, the duties of Enginemen, regular Navy and Naval Reserve, are divided into two specialized groups called emergency service ratings: Diesel Enginemen (END); and Gasoline Enginemen (ENG). The duties in each group are based primarily on the type of engine and the related equipment with which the Engineman must become a specialist.

Specialization of duties is most prevalent in the lower petty officer rates. As a man advances, he must increase his ability and knowledge so that by the time he is qualified for appointment as Chief Engineman he will be an expert in all phases of the general service rating.

Since Naval Reserve components are not normally called to active duty unless mobilization conditions exist, men in the peacetime Reserve study to qualify for the emergency service ratings they would hold in the event of a national emergency. When men in the Reserve are on active duty in peacetime they serve under their emergency ratings. However, if a Reserve Engineman wishes to ship over to the regular Navy in peacetime, he must meet all the requirements of the general service Engineman rating.

Rates

A rate identifies personnel by pay grade. Within a rating, a rate reflects a level of aptitude, training, experience, knowledge, skill, and responsibility; a rate indi-

cates how far you have advanced in whatever work you do. Fireman is a rate and so is chief Engineman. An Engineman third class and a Yeoman third class have the same rates although their ratings, EN and YN, are different. The levels within the Engineman (EN) rating are chief Engineman (ENC); Engineman, first class (EN1); Engineman, second class (EN2); and Engineman, third class (EN3). In other words, within each rating there are steps of advancement; each step provides an increase in pay.

QUALIFICATIONS

You are a member of one of the greatest fighting forces in the world. The United States Navy, responsible for maintaining control of the sea, is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war. As a member of the United States Navy, you will share in this responsibility. As an Engineman striker you will be learning WHAT the Engineman does, WHERE he does it, HOW he does it, and WHY he does it. This training course is designed to aid you in preparing to assume the increasingly greater responsibilities which will be yours as you gain the experience and the knowledge necessary to meet the requirements for advancement.

Requirements

Before you can advance in a rating you must meet certain military and professional requirements. These requirements are published in the *Manual of Qualifications for Advancement in Rating,* NavPers 18068, Revised. This publication is known throughout the Navy as the "Quals Manual," and is an important source of information for the enlisted man who is preparing for advancement; it lists what you have to be able to do and what you are required to know in order to advance. Every ship and station has copies of the Quals Manual.

MILITARY REQUIREMENTS.—Military requirements for advancement are those general qualifications, such as watch standing, first aid, and military conduct, which apply to all enlisted personnel. Before you can advance in rating, you must show that you are proficient in each of the military qualifications specified for the next higher rate. You also may be required to demonstrate your proficiency in the military quals for all the lower pay grades.

The military requirements for enlisted personnel are published as part of the Quals Manual. They are also published and discussed in the *General Training Course for Petty Officers,* NavPers 10055.

PROFESSIONAL REQUIREMENTS.—The professional (technical) qualifications are those which enlisted personnel must have to properly perform the duties of a rate within a particular rating. The higher the rate, the more the man is required to know. A Chief Engineman must have thorough knowledge of every requirement for his rating.

The professional requirements for all Navy enlisted ratings are published in the Quals Manual. These requirements represent the minimum requirements for advancement. For your convenience, the section of the professional requirements that applies to the Engineman rating has been reproduced as Appendix II of this training course. That section has been used as a guide in the preparation of this training course; it will be used as a guide by those who prepare your service-wide competitive examinations. Turn to the back of this training course and become familiar with the qualifications for advancement in the Engineman rating.

Types of Quals

Appendix II lists the professional qualifications for Engineman of every rate (3, 2, 1 and C). Notice that these quals are divided into two principal sections: practical factors (100 series); and examination subjects (200 series). The quals in each of these sections are subdivided

into three groups: operational; maintenance and repair; and administrative and/or clerical.

PRACTICAL FACTORS.—Practical factors are those qualifications which indicate jobs that an Engineman is required to DO in order to advance. The fact that you have a knowledge of such jobs and the ability to accomplish them can best be demonstrated by actually doing the jobs. The EXPERIENCE you get every day on the job will aid you in qualifying for the practical factors.

Before you can take the service-wide examination for advancement in rating, there must be an entry in your service record to prove that you have qualified in the required practical factors. There is a special checkoff sheet which lists all the practical factors for the rate to which you are preparing to advance. This sheet is kept by your leading petty officer or your division officer. When you qualify for any practical factor, the date of satisfactory qualification is recorded and initialed. If you are transferred before you qualify in all factors, the checkoff sheet accompanies your record to the next duty station.

EXAMINATION SUBJECTS.—The qualifications which identify the subject-matter knowledge which is essential to satisfactory performance of the practical requirements, are referred to as examination subjects. The subject matter you must KNOW in order to DO a job can be learned best by STUDY. Your knowledge of the examination subjects can be most accurately determined by written examination. It is for this reason that the examination subjects represent the professional qualifications upon which the service-wide examinations are based. Since you must have a knowledge of the examination subjects in order to satisfactorily qualify in the practical factors, it is advisable that you make a thorough review of both the practical factors and the related examination subjects when you are preparing for an examination for advancement.

THE ENGINEMAN RATING

From your experience as a Fireman, you are well aware of the fact that it takes more than Enginemen to accomplish all of the jobs that must be done in the Navy. (See fig. 1–1.) Note that even in the group (Engineering and Hull) which you have chosen for your occupational career in the Navy, there are ten other ratings: Machinist's Mate, Machinery Repairman, Boilerman, Electrician's Mate, I. C. Electrician, Metalsmith, Pipe Fitter, Damage Controlman, Patternmaker, and Molder. Men in these ratings and in your rating work together as a team to perform their share of the Navy's job. Since the tasks required of men in each of these ratings are equally important to the overall responsibility of the Navy, you must learn to do your job well in order that you can assume your full share of the total responsibility.

Duties of the Engineman

As a qualified boat engineer, you are familiar with some of the duties and responsibilities of the Engineman. The duties and responsibilities which you have learned to assume as a Fireman, however, are only a few of those which you must be able to assume as you advance in the Engineman rating.

The specific duties of an Engineman will vary, depending upon his duty station. In general, however, Engineman's responsibilities include the operation and maintenance of power plants which operate shipboard auxiliaries and of those which propel boats and ships. In addition, Enginemen must know how to operate, maintain, and repair many kinds of shipboard auxiliary equipment. Such equipment includes distilling units, refrigeration and air-conditioning systems, pumps, air compressors, and various kinds of hydraulic equipment. In order to perform their duties efficiently, Enginemen must have a thorough understanding of the principles of operation of the equipment with which they are required to work;

in addition, they must have a general knowledge of the overall operation of the division and of the ship to which they are assigned. These, in brief, are the overall requirements of the rating for which you are striking. In order to advance to chief in the general service Engineman rating a man must be able to satisfactorily meet all the practical requirements and have a thorough knowledge of all the examination subjects listed in Appendix II.

Duties of the EN3

Careful study of the quals for EN3 (appendix II) will show that you will have to learn to do a variety of jobs. In brief, you will have to learn to perform duties required in the routine operation and maintenance of Diesel, gasoline, gas turbine, and auxiliary machinery. You will be required to assist in starting and stopping machinery by manipulating valves, levers, or switches. You will accomplish minor repairs, such as repacking valves and pumps and renewing gaskets. You will assist in overhauling pumps, valves, piping systems, and propulsion and auxiliary engines. You will be required to stand watches on steering engines, distilling units, and refrigeration and air-conditioning systems.

As you prepare for advancement, the best training you can get comes from working with all the various units of engineroom equipment, learning all you can by actual EXPERIENCE. There is no substitute for the first-hand information that you gain in this way. Books, manuals, and pictures cannot take the place of the "know how" that you acquire by actually working on a machine. If your ship lacks certain machines of which you are expected to have a knowledge, arrange to observe and study these machines on another ship. As an active-duty striker, you will never be far from the equipment and machinery you must know how to operate and maintain. If you are in reserve status, your opportunities to work with late-

model machinery and equipment will be limited. In this case, make the best use of your annual active duty for training purposes.

Practical experience, however, does not provide all that is necessary for advancement. Even though much "know how" is required in the engineroom, a great deal of "know why" is also necessary. As a general rule, an understanding of the principles of operation of a machine can best be attained by reading and STUDY. Knowing why a machine operates the way it does increases your ability to operate, maintain, and repair the machine; and to determine the causes of faulty operation. In an emergency, a man who only knows HOW to do something is not likely to be as useful as a man who knows how to do it and WHY it should be done. Therefore, in addition to learning all you can from practical experience, it is necessary that you be familiar with and make use of available sources of information which will help you in your preparation for advancement.

SOURCES OF INFORMATION

One of the most valuable things you can learn about any subject is how to find out more about it. You should know where to look for current, accurate, authoritative information concerning all of the equipment and machinery with which you will be working. Much of the information which you will need to know to meet the requirements for advancement is contained in this training course. Since no one book can present everything you will need to know to qualify for advancement, however, additional sources of information are listed in this chapter.

This Training Course

The purpose of this training course is to provide information which will aid you in meeting the professional

(technical) qualifications for advancement to EN3. This course explains and illustrates many of the machines with which you will be working. The contents of this course deal mainly with the "know why" aspects of your work; however, insofar as possible, information that will aid you in meeting the practical factors applicable to the EN3 rate has also been included.

To make the most effective use of this course, always try to combine the knowledge that you gain from study with the knowledge that comes from practical experience and from actual observation of the machinery itself.

In order to present the information in the most logical sequence for study purposes, this training course has been divided into two sections. Section I (chapters 2 through 15) provides information on engines and related equipment. Section II (chapters 16 through 19) of this course deals with the shipboard auxiliary equipment with which you will be concerned.

Use the table of contents and the index of this course when you are looking for information related to a particular qual. Take quals 201.7 and 201.8, for example. (See appendix II.) By referring to the table of contents and to the index, you will find that several of the items included under these two quals are taken up in chapter 2 of this training course. When supplementary information related to a particular qual may be found in other publications, reference is made in this course to such sources of information.

Special notice should be taken of the abbreviations which are used in this course to identify the various engines that are discussed. These abbreviations are used to avoid frequent repetition of lengthy identifying titles. The engines referred to and the abbreviations used in this course to identify them are given in the accompanying table.

Abbreviations	*Engines*
GSB–8	Cooper-Bessemer Direct-Reversible Diesel Engine, Model GSB–8.
Cummins H	Cummins Diesel Engine, Model H.
FM 38D	Fairbanks-Morse Opposed-Piston Diesel Engine, Model 38D8 1/8.
FM 38E	Fairbanks-Morse Opposed-Piston Diesel Engine, Model 38E5 1/4.
GM 71; GM 6–71	General Motors Six-cylinder, Series 71, Two-stroke Cycle Diesel Engine.
GM 268A	General Motors Diesel Engine, 268A Models.
GM 278A; GM 16–278A	General Motors Diesel Engine, 278A Models.
GM 567; GM 12–567	General Motors Diesel Engine, Model 12–567.
Gray Marine	Gray Marine Six-cylinder Diesel Engine, Models 64, 65, and 66.
Six–D427	Gray Marine Diesel Engine, Model Six–D427.
Hercules, DWXD	Hercules Diesel Engine, Model DWXD.
Packard Diesel, Series 142	Packard Diesel Marine Engines, Series 142, Models 2D–850–R and 1D–1700–T.

At the end of each chapter of this training course there is a quiz, which you should use in checking on what you have learned from your study of the material in the chapter. The answers to each quiz are in appendix I. Attempt to answer the questions before looking at the answers in the appendix. If there are any you cannot answer correctly and with confidence, go over the subject matter again. If you are still in doubt about the subject, ask your leading petty officer to explain the material to you. He will be glad to help you; one of his duties (a future duty of yours) is to help the Navy train good Enginemen.

Additional Sources of Information

Publications providing information which supplements that contained in this training course may be obtained from your Information and Education Officer. Some sources of information which may be helpful to you as you prepare for advancement are:

Atomic Warfare Defense, NavPers 10097
Basic Electricity, NavPers 10086
Basic Hand Tool Skills, NavPers 10085
Basic Hydraulics, NavPers 16193
Basic Machines, NavPers 10624
Bureau of Ships Manual
  Chapter 41—Main Propelling Machinery (Section II, Diesel Engines; and Section V, Gasoline Engines)
  Chapter 45—Lubricants and Lubrication Systems
  Chapter 58—Distilling Plants
Fireman, NavPers 10520-A
Fundamentals of Diesel Engines, NavPers 16178-A
Mathematics, Vol. 1, NavPers 10069-A
Mathematics, Vol. 2, NavPers 10070-A
Standard First Aid Training Course, NavPers 10081.

Most of the publications listed above are revised at frequent intervals, in order to bring the material up-to-date. When consulting any reference material, be sure that you are using the most recent, revised edition available. The current *List of Training Publications*, NavPers 10061, gives the titles, NavPers numbers, and latest-edition dates of available Navy training courses. This list is revised about twice a year; be sure to consult the most recent edition. Other publications which you can check for information on available training courses include *The Naval Training Bulletin*, *All Hands*, and *The Naval Reservist*. A pamphlet entitled *Training Courses and Publications for General Service Ratings*, NavPers 10052, contains a list of mandatory and recommended material

to be studied by enlisted personnel preparing for advancement in rating. This pamphlet is revised about twice a year; be sure you get the most recent edition.

The manufacturers' instruction books which are furnished with most machinery units are valuable sources of information on operation, maintenance, and repair. Machinery handbooks and marine engineering handbooks should also be kept in mind as possible sources of information.

TRAINING TO BE A LEADER

As an EN striker you are in training to become more than just a skilled specialist in an occupational rating. As you know, any advancement in rating requires a corresponding increase in knowledge and skill, in willingness to assume responsibility, and in ability to supervise men. As an EN3, you will have greater authority than you have had before; you must, therefore, assume more responsibility. As you advance in the Engineman rating, your military duties become more important. You will have an increasing responsibility for showing other men what to do and how to do it, and for checking their work. You will be expected to provide the supervision and instruction which those men need to advance in their rating. In brief, as a petty officer you are in training to be a leader as well as a technical specialist.

In order to be a good leader, you must be capable of obtaining willing effort and teamwork from a group. Everything you do and say that makes those under your supervision have confidence in you and carry out your orders to the best of their ability is leadership. As a striker you are not expected to be as skilled in the art of leadership as are higher-rated men; you are in training to learn this art. Once you become a petty officer you are considered potential leader material; in your present rate, then, it is important that you make a sincere effort to develop the qualities of a good leader. Keep in mind

that with each advancement in rating you should be capable of assuming greater responsibility and authority as a leader of lower-rated men.

Two chapters of the *General Training Course for Petty Officers,* NavPers 10055, have been devoted to the subject of leadership as it applies to you. As you prepare for advancement, it is advisable that you review in that reference the subjects of Military Leadership and The Petty Officer as a Leader; many of the qualities of a good leader are discussed. Study these qualities carefully; keep them in mind as you prepare for advancement.

The *General Training Course for Petty Officers* does not cover the subject of leadership completely; it does, however, consider the important qualities which every petty officer must possess to be a good leader. These qualities are discussed briefly in the following paragraphs.

A petty officer's success depends upon the men under him. By assuming full responsibility for the men under you, by intelligently planning the work they perform, by treating them so they will work hard and perform their work willingly, you will gain their respect; as a result, you will obtain the most from the men under your supervision.

As you learn to become a leader, there are a number of things you must do. You must know your job, and teach your men their jobs; you must know the men you supervise, and treat each one according to his own capacity; you must analyze the work to be done, and assign it properly; and you must take full responsibility for the completed job. Above all, you must be enthusiastic about your work; develop pride in the men under you and obtain full cooperation from them as a group.

Use this brief discussion of leadership and the related material in the *General Training Course for Petty Officers* as the starting point for a continuing study of leadership. Always remember, as you prepare for advancement, that

leadership concerns you; it is going to have a direct bearing on your success as a petty officer.

Your military and professional (technical) qualifications as an Engineman will not go unnoticed. You can advance to chief and even higher if you apply yourself; the road of advancement, however, is not an easy one. Advancement requires much study and training; it requires a willingness to learn and to work. Do you have this willingness? The Navy thinks so: otherwise, you would not have been designated a striker. Prove that you have what it takes to advance. The progress you make will be up to you.

REWARDS OF ADVANCEMENT

Each time you advance in rating you receive many rewards. Only a few of these are better pay and allowances, opportunities for more interesting and challenging assignments, more pay when you retire, and greater respect from your superiors and from those you supervise.

As a member of the greatest Navy in the world, you have the satisfaction of knowing that, as you steadily advance, you are SERVING YOUR COUNTRY in a most important way. Do your job well and take PRIDE in what you do. Service to your country is a special privilege; serve with HONOR.

Tradition, valor, and victory are the Navy's heritage. The long history of outstanding achievements and noble service of the Navy provides an inspiration and a challenge to you and your shipmates. It is up to you to help maintain and enlarge the prestige and the traditions of the Naval service.

QUIZ

1. How are Navy enlisted men's occupations identified?
2. Name the Engineman emergency service ratings.
3. Men in the regular Navy hold ratings in what type of service in peacetime? In wartime?
4. A naval Reservist on active duty in peacetime holds a rating in what type of service?
5. How does the work required by an EN emergency service rating differ from that required by the EN general service rating?
6. How does a rate differ from a rating?
7. What types of professional qualifications will you be required to meet in order to qualify for advancement?
8. What are practical factors?
9. What is an examination subject?
10. In what two ways will you learn the things you need to know for advancement?
11. From whom can you obtain the publications which are needed to supplement this training course?
12. What precaution should be taken before you use a publication as a source of information?

SECTION I

INTERNAL COMBUSTION ENGINES

Types

Parts and Systems

Fuels and Lubricants

Transmission of power

Operation and Maintenance

CHAPTER 2

THE ENGINES

The engines with which you have come in contact have provided a means for gaining experience as well as for acquiring a better understanding of the machines you will be required to operate and maintain. You have learned to do many routine maintenance tasks and probably have had a hand in helping do some overhaul and repair jobs. Any experience you have had will be beneficial in meeting the professional requirements of the Engineman rating. Even though your past experience has improved your understanding of the internal combustion engine, there are probably many factors dealing with engines and their operation which you do not fully understand. A thorough understanding will require a great deal more practical experience as well as considerably more study. This course will serve as one source of information for additional study. The basic principles covered in the training courses and publications listed as mandatory and recommended for Fireman and Engineman 3 in the latest revision of NavPers 10052, *Training Courses and Publications for General Service Ratings,* will not be covered in detail in this course. Instead, supplementary information is provided which will aid you in meeting professional requirements.

This chapter provides background information for the chapters which follow. It deals mainly with variations in engines and the operating principles involved. A knowledge of the principles of operation is necessary if one is

to fully understand why a machine does or does not function properly. Several of the principles dealing with engines and the internal combustion process were introduced to you in the training course, *Fireman,* NavPers 10520-A. This course defines and explains many terms such as engine, reciprocating engine, internal combustion engine, heat, energy, work and power, pressure and volume of gas, adiabatic process, spark ignition, compression ignition, 4- and 2-stroke cycles, and compression ratio. These terms are not all discussed in NavPers 10520-A directly in connection with internal combustion engines. Nevertheless, many of the principles dealing with mechanics and heat will apply to many of the machines which you will be operating and maintaining.

Your experience probably has been in connection with reciprocating-type internal combustion engines—Diesel and gasoline. In the future, you may come in contact with a different type of internal combustion engine—the gas turbine. Though this type engine is not new, its application to marine use in the Navy is relatively recent. Since the majority of the engines in service in the Navy are of the reciprocating type, the following discussion will be more extensive on engines of this type. Subsequent training courses for Enginemen may include additional information on gas turbines, depending upon the degree of responsibility required of the Engineman in operating and maintaining this type engine.

RECIPROCATING INTERNAL COMBUSTION ENGINES

The engines with which you will be working are machines which convert heat energy into work by burning fuel in a confined chamber; thus the term INTERNAL COMBUSTION. Since the pistons in Diesel and gasoline engines employ a back-and-forth motion, they are also classified as RECIPROCATING engines. The qualifications for advancement in rating indicate that you must know a great deal about engines of this type. Some of the required factors (see quals 201-7 and 201-8, appendix II) have been intro-

duced and explained in the training course, *Fireman,* NavPers 10520-A. Others are introduced in the text, *Fundamentals of Diesel Engines, U. S. Navy,* NavPers 16178A. Additional information is provided here which will aid you in understanding the difference between the various types of engines. At the same time, the information given here should make the principles by which an engine operates more easily understood. If you know the difference between engines and the principles involved in the operation of the engines, you will be better qualified to operate and maintain them.

Cycles of Operation

The operation of an engine involves the admission of fuel and air into a combustion space and the compression and ignition of the charge. The resulting combustion releases gases and increases the temperature within the space. As temperature increases, pressure increases and forces the piston to move. This movement is transmitted through a chain of parts to a shaft. The resulting rotary motion of the shaft is utilized for work; thus, heat energy is transformed into mechanical energy. In order for the process to be continuous, the expanded gases must be removed from the combustion space, a new charge admitted, and then the process repeated.

If you recheck the process of engine operation, starting with the admission of air and fuel and following through to the removal of the expended gases, you will note that a series of events or phases takes place. The term cycle identifies the sequence of events that takes place in the cylinder of an engine for each power impulse transmitted to the crankshaft. These events always occur in the same order each time the cycle is repeated. The number of events occurring in a cycle of operation will depend upon the engine type—Diesel or gasoline. The difference in the number of events occurring in the cycle of operation for these engines is shown in the table on page 22.

The events and their sequence in a cycle of operation for a:	
DIESEL ENGINE	GASOLINE ENGINE
INTAKE of air	INTAKE of fuel and air.
COMPRESSION of air	COMPRESSION of fuel-air mixture.
INJECTION of fuel	
IGNITION and COMBUSTION of charge.	IGNITION and COMBUSTION of charge.
EXPANSION of gases	EXPANSION of gases.
REMOVAL of waste	REMOVAL of waste.

The principal difference, as shown in the table, in the cycles of operation for Diesel and gasoline engines involves the admission of fuel and air to the cylinder. While this takes place as one event in the operating cycle of a gasoline engine, it involves two events in Diesel engines. Thus, insofar as events are concerned, there are six main events taking place in the Diesel cycle of operation and five in the cycle of a gasoline engine. This is pointed out in order to emphasize the fact that the events which take place and the piston strokes which occur during a cycle of operation are not identical. Even though the events of a cycle are closely related to piston position and movement, all of the events will take place during the cycle regardless of the number of piston strokes involved. The relationship of events and piston strokes is discussed later in this chapter under a separate heading.

From the preceding discussion, it is apparent that a cycle of operation in either a Diesel or gasoline engine involves two basic factors—heat and mechanics. Any explanation of the relationship of heat to the motion of the engine parts—that is, the means by which heat energy is transformed into mechanical energy—will involve many terms such as matter, molecule, energy, heat, temperature, the mechanical equivalent of heat, force, pres-

sure, volume, work, and power. (If you need review on these terms, see the appropriate sections of *Fireman*, NavPers 10520-A; *Basic Machines*, NavPers 10624; *Fundamentals of Diesel Engines, U. S. Navy*, NavPers 16178A; or any good elementary physics text.)

The mechanics of engine operation is sometimes referred to as the MECHANICAL or operating CYCLE of an engine; while the heat process which produces the forces that move engine parts may be referred to as the COMBUSTION CYCLE. A cycle of each type is included in a cycle of engine operation.

Mechanical Cycles

In the preceding section, the events taking place in a cycle of engine operation were emphasized. Little was said about piston strokes except that a complete sequence of events would occur during a cycle regardless of the number of strokes made by the piston. The number of piston strokes occurring during any one series of events is limited to either two or four, depending upon the design of the engine. Thus, we have the 4-stroke cycle and the 2-stroke cycle. These cycles are known as the mechanical cycles of operation.

FOUR- AND TWO-STROKE CYCLES.—You should be familiar with these cycles already since they are both explained in *Fireman*, NavPers 10520-A. You will recall that the terms "four-stroke" and "two-stroke" identify the number of strokes the piston makes during a cycle of events; also, that both types of mechanical cycles are used in both types of reciprocating engines. However, most gasoline engines in Navy service operate on the 4-stroke cycle and you will find that a greater number of Diesels operate on the 2-stroke than on the 4-stroke cycle. Since you may be required to operate and maintain engines operating on either of the mechanical cycles, you should be familiar with the principal differences in these cycles. The relationship of the events and piston strokes occurring in a cycle of operation involves some

of these differences. A thorough understanding of this relationship will aid you in carrying out your duties in connection with engine operation and maintenance.

RELATIONSHIP OF EVENTS AND STROKES IN A CYCLE.—A review of the discussion and illustrations of engine operating cycles (*Fireman,* NavPers 10520-A) will reveal that a piston stroke is the distance a piston moves between limits of travel. It is also pointed out that the cycle of operation in an engine operating on the 4-stroke cycle involves 4 piston strokes—INTAKE, COMPRESSION, POWER, and EXHAUST. In the case of the 2-stroke cycle, only 2 strokes are mentioned—POWER AND COMPRESSION.

If we recheck the table (shown earlier in this chapter) listing the series of events which take place during the cycles of operation of Diesel and gasoline engines, we find that the strokes are named to correspond to some of the events. However, since six events are listed for Diesel engines and five events for gasoline engines, it is evident that more than one event takes place during some of the strokes, especially in the case of the 2-stroke cycle. Even though this is the case, it is common practice to identify some of the events as strokes of the piston. This is because such events as intake, compression, power, and exhaust in a 4-stroke cycle involve at least a major portion of a stroke and, in some cases, more than one stroke. The same is true of power and compression events and strokes in a 2-stroke cycle. Such association of events and strokes overlooks other events taking place during a cycle of operation. This oversight sometimes leads to confusion when one studies the operation of an engine or deals with maintenance problems involving the timing of ignition systems or fuel injection systems.

This discussion points out the relationship of events to strokes by covering the number of events occurring during a specific stroke, the duration of an event with respect to a piston stroke, and the cases where one event overlaps another. The relationship of events to strokes

can be shown best by making use of graphic representation of the changing situation occurring in a cylinder during a cycle of operation. Figure 2-1 illustrates these changes for a 4-STROKE CYCLE DIESEL ENGINE.

The relationship of events to strokes is more readily understood, if the movements of a piston and its crankshaft are considered first. In *A* of figure 2-1, the reciprocating motion and stroke of a piston are indicated and the rotary motion of the crank during two piston strokes is shown. The positions of the piston and crank at the start and end of a stroke are marked "top" and "bottom," respectively. If these positions and movements are marked on a circle (*B*, fig. 2-1), the piston position, when at the top of a stroke, is located at the top of the circle. When the piston is at the bottom of a stroke, the piston position is located at the bottom center of the circle. Top center and bottom center are two terms which you will encounter frequently when learning to time ignition systems and fuel injection systems. Note in *A* and *B* of figure 2-1 that top center and bottom center identify points where changes in direction of motion take place. In other words, when the piston is at top center, upward motion has stopped and downward motion is ready to start or, with respect to motion, the piston is "dead." The points which designate changes in direction of motion for a piston and crank are frequently called TOP DEAD CENTER (TDC) and BOTTOM DEAD CENTER (BDC).

If the circle illustrated in *B* is broken at various points and "spread out" (*C*, fig. 2–1), the events of a cycle and their relationship to the strokes and how some of the events of the cycle overlap can be shown. TDC and BDC should be kept in mind since they identify the start and end of a STROKE and they are the points from which the start and end of EVENTS are established.

By following the strokes and events as illustrated, it can be noted that the intake event starts before TDC, or before the actual down stroke (intake) starts, and

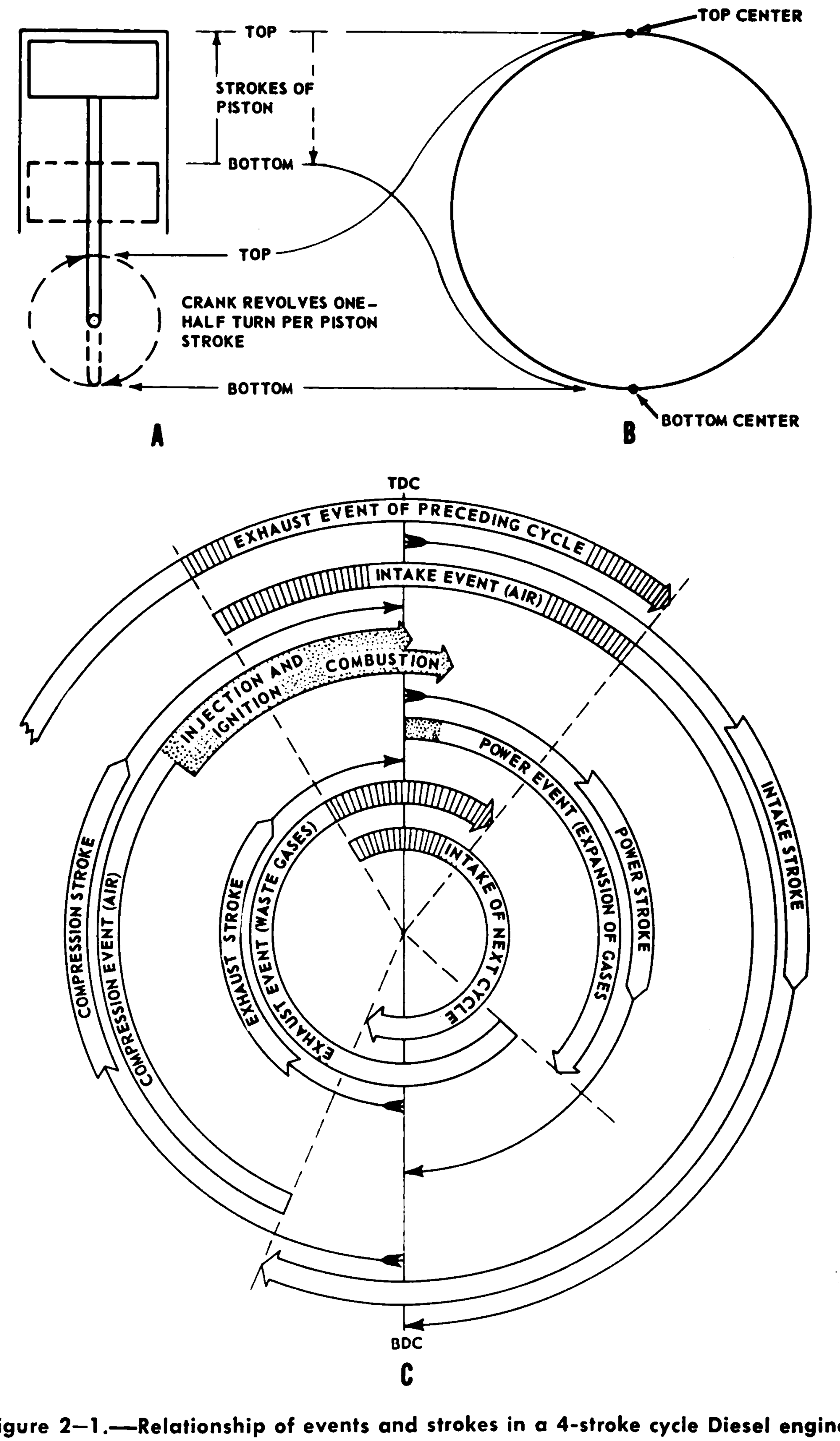


Figure 2–1.—Relationship of events and strokes in a 4-stroke cycle Diesel engine.

continues on past BDC, or beyond the end of the stroke. The compression event starts when the intake event ends, but the upstroke (compression) has been in process since BDC. The injection and ignition events overlap with the latter part of the compression event, which ends at TDC. The burning of the fuel continues a few degrees past TDC. The power event or expansion of gases ends several degrees before the down (power) stroke ends at BDC. The exhaust event starts when the power event ends and continues through the complete upstroke (exhaust) and past TDC. Note the overlap of the exhaust event with the intake event of the next cycle. The details on why certain events overlap and why some events are shorter or longer with respect to strokes will be covered later in this course.

From the preceding discussion, it can be seen why the term "stroke" is sometimes used to identify an event which occurs in a cycle of operation. However, it is best to keep in mind that a stroke involves 180° of crankshaft rotation (or piston movement between dead centers) while the corresponding event may take place during a greater or lesser number of degrees of shaft rotation.

The relationship of events to strokes in a 2-STROKE CYCLE DIESEL ENGINE is shown in figure 2-2. Comparison of figures 2–1 and 2–2 reveals a number of differences between the two types of mechanical or operating cycles. These differences are not too difficult to understand if one keeps in mind that four piston strokes and 720° of crankshaft rotation are involved in the 4-stroke cycle while only half as many strokes and degrees are involved in a 2-stroke cycle. Reference to the cross-sectional illustrations (fig. 2–2) will aid in associating the event with the relative position of the piston. Even though the two piston strokes are frequently referred to as power and compression, they are identified as the "down stroke" (TDC to BDC) and "up stroke" (BDC to TDC) in this discussion in order to avoid confusion when reference is made to an event.

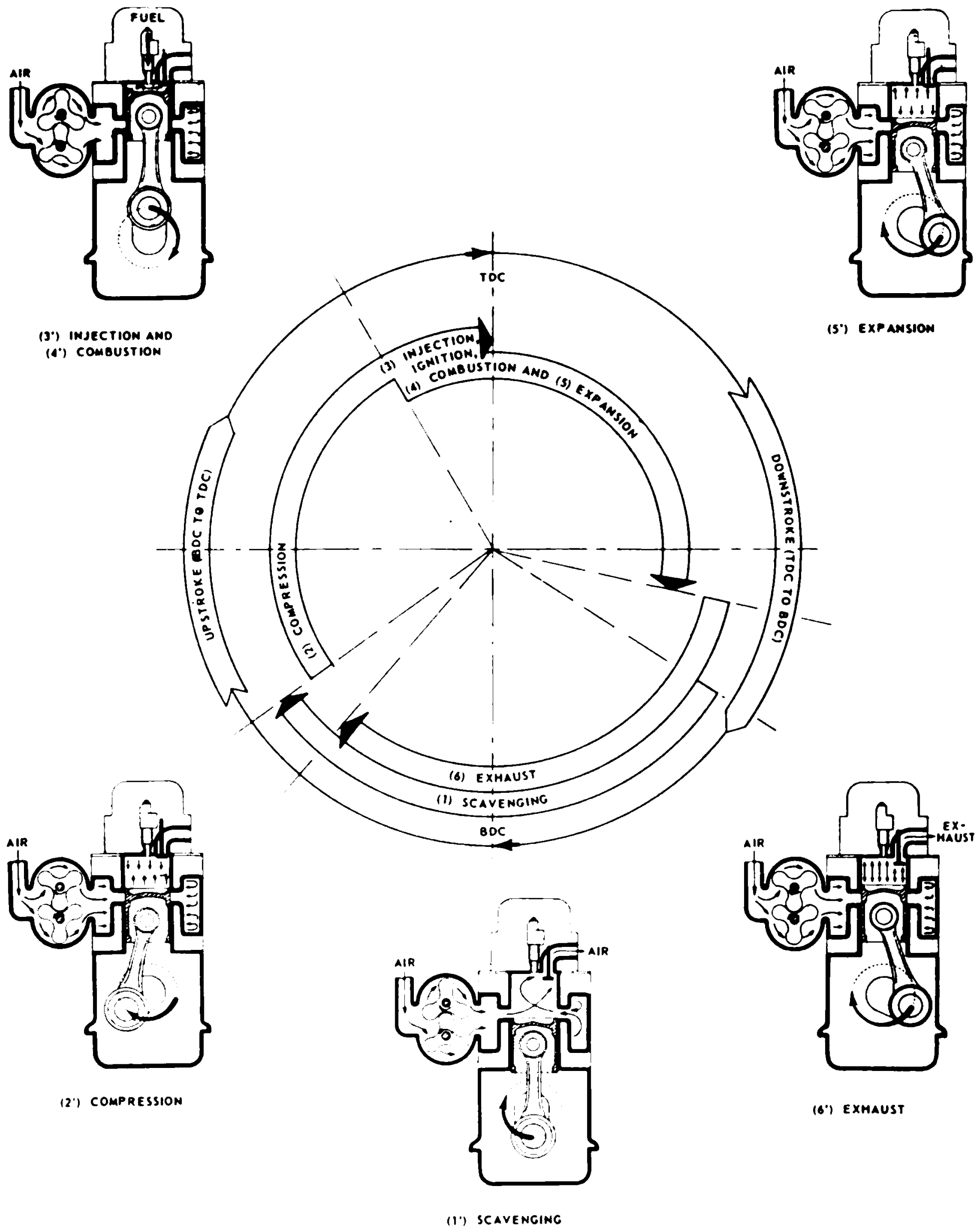


Figure 2–2.—Strokes and events of a 2-stroke cycle Diesel engine.

Starting with the admission of air, (1) figure 2–2, we find that the piston is in the lower half of the down stroke and that the exhaust event (6) is in process. The exhaust event started (6′) a number of degrees before intake, both starting several degrees before the piston reaches BDC. The overlap of these events is necessary in order that the incoming air (1′) can aid in clearing the

cylinder of exhaust gases. Note that the exhaust event stops a few degrees before the intake event stops, but several degrees after the upstroke of the piston has started. (The exhaust event in some 2-stroke cycle Diesel engines ends a few degrees after the intake event ends.) When the scavenging event ends, the cylinder is charged with the air which is to be compressed. The compression event (2) an (2′) takes place during the major portion of the upstroke. The injection event (3) and (3′) and ignition and combustion (4) and (4′) occur during the latter part of the upstroke. (The point at which injection ends varies with engines. In some cases, it ends before TDC; in others, a few degrees after TDC.) The intense heat generated during the compression of the air ignites the fuel-air mixture and the pressure resulting from combustion forces the piston down. The expansion (5 and 5′) of the gases continues through a major portion of the down stroke. After the force of the gases has been expended, the exhaust valve opens (6′) and permits the burned gases to enter the exhaust manifold. As the piston moves downward, the intake ports are uncovered (1′) and the incoming air clears the cylinder of the remaining exhaust gases and fills the cylinder with a fresh air charge (1); thus, the cycle of operation has started again.

Now, what is the difference between the 2- and 4-stroke cycles? From the standpoint of the mechanics of operation, the principal difference is in the number of piston strokes taking place during the cycle of events. A more significant difference is the fact that a 2-stroke cycle engine delivers twice as many power impulses to the crankshaft for every 720° of shaft rotation. (See fig. 2–3.)

Diagrams showing the mechanical cycles of operation in GASOLINE ENGINES would be somewhat similar to those described for Diesel engines, except that there would be one less event taking place during the gasoline engine cycle. Since air and fuel are admitted to the cylinder of a gasoline engine as a mixture during the intake event, the injection event does not apply.

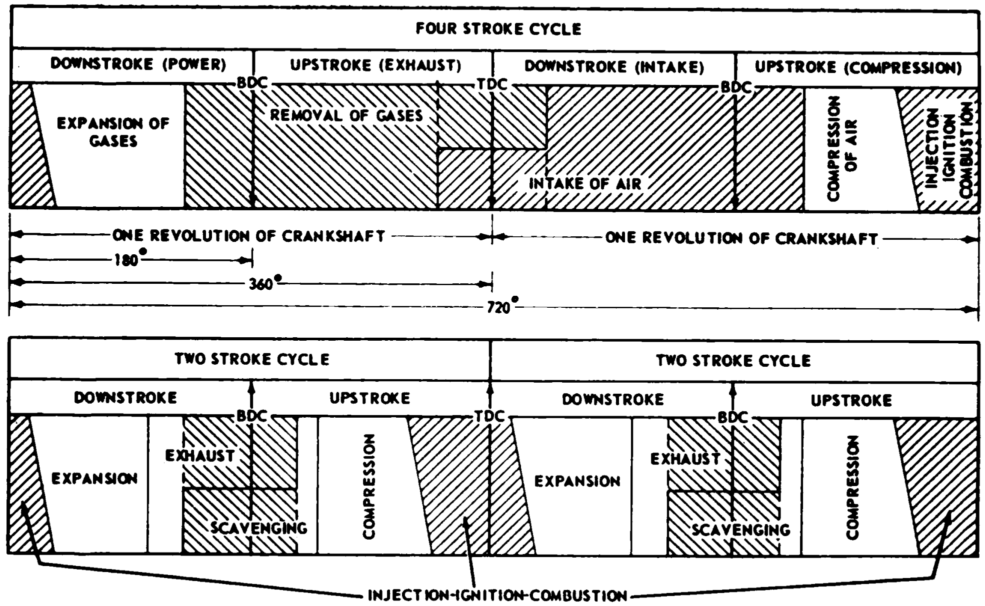


Figure 2–3.—Comparison of the 2- and 4-stroke cycles.

The figures shown here representing the cycles of operation are for illustrative purposes only. The exact number of degrees before or after TDC or BDC that an event starts and ends will vary between engines. Information on such details should be obtained from appropriate instructions dealing with the specific engine in question.

Combustion Cycles

To this point, the strokes of a piston and the related events taking place during a cycle of operation have been given greater consideration than the heat process involved in the cycle. However, the mechanics of engine operation cannot be discussed without dealing with heat. Such terms as ignition, combustion, and expansion of gases, all indicate that heat is essential to a cycle of engine operation. So far, particular differences between Diesel and gasoline engines have not been pointed out, except the number of events occurring during the cycle of operation. Whether a Diesel engine or a gasoline engine, the 2- or the 4-stroke cycle may apply. Then, one of the principal differences between these types of engines must involve the heat process utilized to produce the forces which make the

engine operate. The heat processes are sometimes called combustion or heat cycles.

The three most common combustion cycles associated with reciprocating internal combustion engines are the OTTO cycle, the TRUE DIESEL cycle and the MODIFIED or SEMI-DIESEL cycle.

Reference to combustion cycles brings up another important difference between gasoline and Diesel engines—COMPRESSION PRESSURE. This factor is directly related to the combustion process utilized in an engine. As you know, Diesel engines have a much higher compression pressure than gasoline engines. The higher compression pressure in Diesels explains the difference in the METHODS OF IGNITION used in gasoline and Diesel engines. Compressing the gases within a cylinder raises the temperature of the confined gases. The greater the compression, the higher the temperature. In a gasoline engine, the compression temperature is always lower than the point where the fuel would ignite spontaneously. Thus, the heat required to ignite the fuel must come from an external source—SPARK IGNITION. On the other hand, the compression temperature in a Diesel engine is far above the ignition point of the fuel oil; therefore, ignition takes place as a result of heat generated by compression of the air within the cylinder—COMPRESSION IGNITION.

The difference in the methods of ignition indicates that there is a basic difference in the combustion cycles upon which Diesel and gasoline engines operate. This difference involves the behavior of the combustion gases under varying conditions of pressure, temperature, and volume. Since this is the case, you should be familiar with the relationship of these factors before considering the combustion cycles individually. (The basic laws and processes involved in a volume, temperature, and pressure relationship are discussed under the properties of gases in NavPers 10520 and NavPers 16178A.)

RELATIONSHIP OF TEMPERATURE, PRESSURE, AND

VOLUME.—The relationship of these three conditions as found in an engine can be illustrated by considering what takes place in a cylinder fitted with a reciprocating piston. (See fig. 2–4.)

Instruments are provided which indicate the pressure

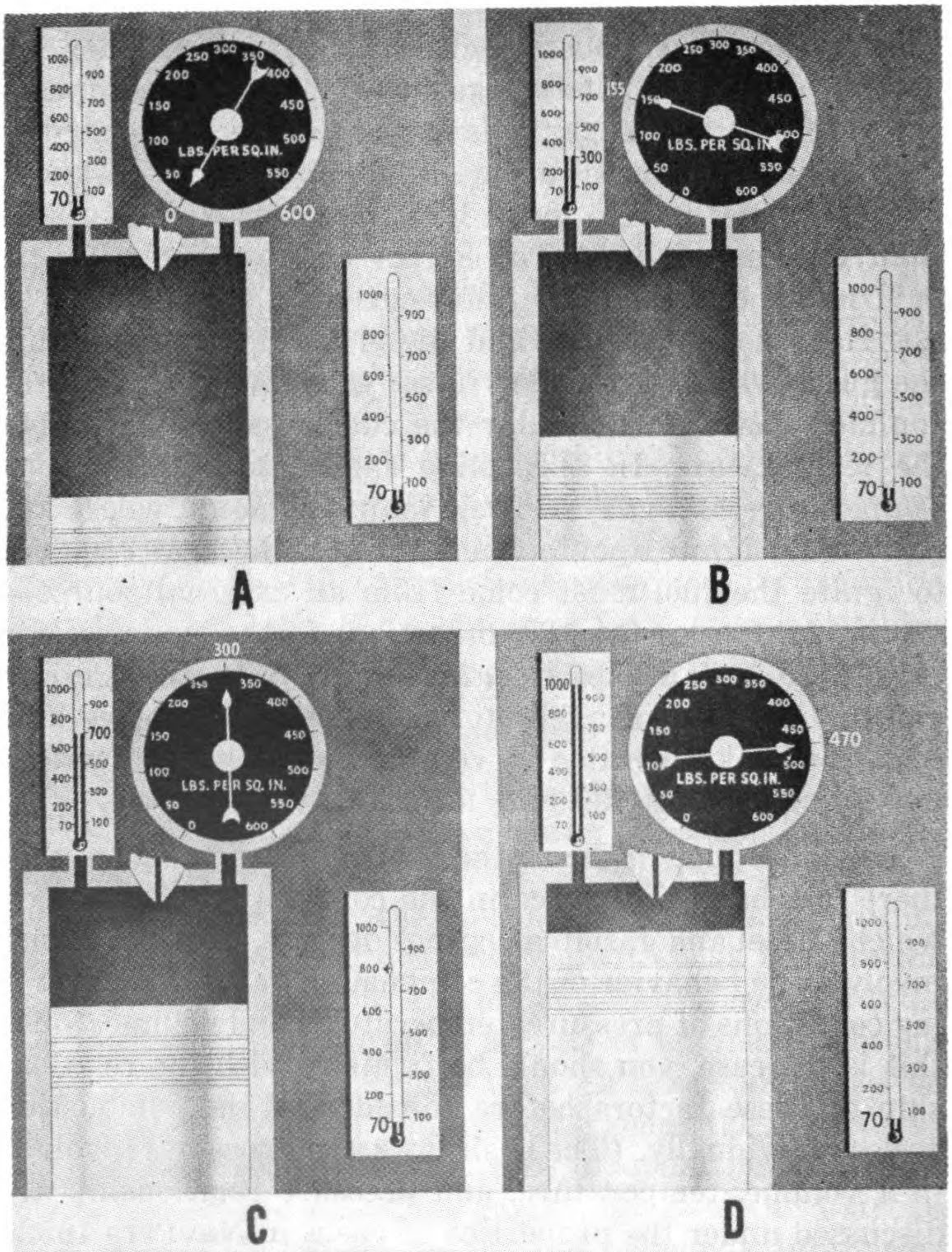


Figure 2–4.—Volume, temperature, and pressure relationship in a cylinder.

within the cylinder and the temperature inside and outside the cylinder. Consider that the air in the cylinder is at atmospheric pressure and that the temperatures, inside and outside the cylinder, are about 70° F. (See fig. 2–4A.)

If the cylinder is an airtight container and a force pushes the piston toward the top of the cylinder, the entrapped charge will be compressed. As the compression progresses, the VOLUME of the air DECREASES, the PRESSURE INCREASES, and the TEMPERATURE RISES (see B and C). These changing conditions continue as the piston moves and when the piston nears TDC (see D) we find that there has been a marked decrease in volume, and that both pressure and temperature are much greater than at the beginning of compression. Note that pressure has gone from 0 to 470 psi and temperature has increased from 70° to about 1000° F. These changing conditions indicate that mechanical energy, in the form of force applied to the piston, has been transformed into heat energy in the compressed air. The temperature of the air has been raised sufficiently to cause ignition of fuel injected into the cylinder.

Further changes take place after ignition. Since ignition occurs shortly before TDC, there is little change in volume until the piston passes TDC. However, there is a sharp increase in pressure and temperature shortly after ignition takes place. The increased pressure forces the piston downward. As the piston moves downward, the gases expand, or increase in volume, and pressure and temperature decrease rapidly. The changes in volume, pressure, and temperature, described and illustrated here, are representative of the changing conditions in the cylinder of a modern Diesel engine.

The changes in volume and pressure in an engine cylinder can be illustrated by diagrams similar to those shown in figure 2–5. Such diagrams are made by devices which measure and record the pressures at various piston positions during a cycle of engine operation. Diagrams

which show the relationship between pressures and corresponding piston positions are called PRESSURE-VOLUME DIAGRAMS or INDICATOR CARDS.

On diagrams which provide a graphic representation of cylinder pressure as related to volume, the vertical line *P* on the diagram (see fig. 2–5) represents pressure and the horizontal line *V* represents volume. When a diagram is used as an indicator card, the pressure line is marked off in units of pressure and the volume line is marked off in inches. Thus, the volume line could be used to show the length of the piston stroke which is proportional to volume. The distance between adjacent letters on each of the diagrams (fig. 2–5) represents an event of a combustion cycle; that is compression of air, burning of the charge, expansion of gas, and removal of gases.

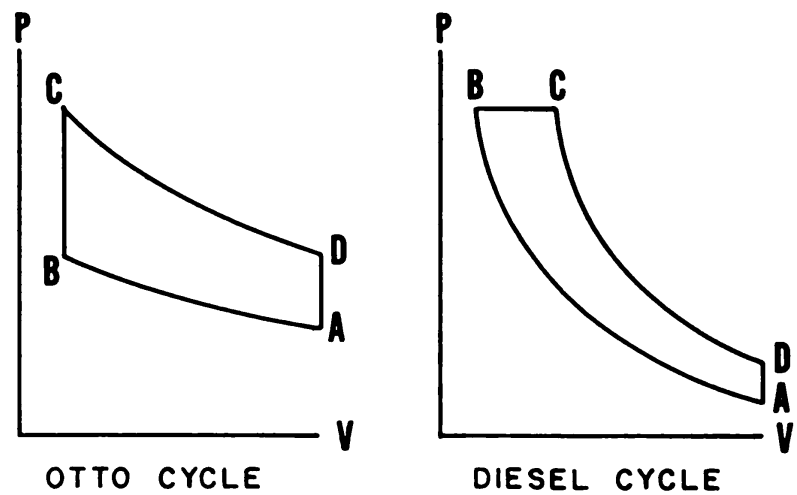


Figure 2–5.—Pressure-volume diagrams for theoretical combustion cycles.

The diagrams shown in figure 2–5 provide a means by which the Otto and true Diesel combustion cycles can be compared. Reference to the diagrams during the following discussion of these combustion cycles will aid you in identifying the principal differences existing between the cycles. The diagrams shown are theoretical pressure-volume diagrams. Diagrams representing conditions in operating engines are given later. Information obtained

from actual indicator diagrams may be used in checking engine performance.

OTTO (CONSTANT-VOLUME) CYCLE.—In theory, this combustion cycle is one in which combustion, induced by spark ignition, occurs at constant volume. The Otto cycle and its principles serve as the basis for modern gasoline engine designs.

Compression (see line *A–B*, fig. 2–5) of the charge in the cylinder is adiabatic. Spark ignition occurs at *B*, and, due to the volatility of the mixture, combustion practically amounts to an explosion. Combustion, represented by line *BC*, occurs (theoretically) just as the piston reaches TDC. During combustion, there is no piston travel; thus, there is no change in the volume of the gas in the cylinder. This accounts for the descriptive term, CONSTANT VOLUME. During combustion, there is a rapid rise of temperature followed by a pressure increase which performs the work during the expansion phase, represented by line *CD*. The removal of gases, represented by line *DA*, is at constant volume.

TRUE DIESEL (CONSTANT-PRESSURE) CYCLE (See fig. 2–5).—This cycle may be defined as one in which combustion, induced by compression ignition, theoretically occurs at a constant pressure. Adiabatic compression (represented by line *AB*) of the air increases its temperature to a point where ignition occurs automatically when the fuel is injected. Fuel injection and combustion are so controlled as to give constant-pressure combustion (represented by line *BC*). This is followed by adiabatic expansion (represented by line *CD*) and constant volume rejection of the gases (represented by the line *DA*).

In the true Diesel cycle, the burning of the mixture of fuel and compressed air is a relatively slow process when compared with the quick, explosive-type combustion process of the Otto cycle. The injected fuel penetrates the compressed air, some of the fuel ignites, then the rest of the charge burns. The expansion of the gases keeps

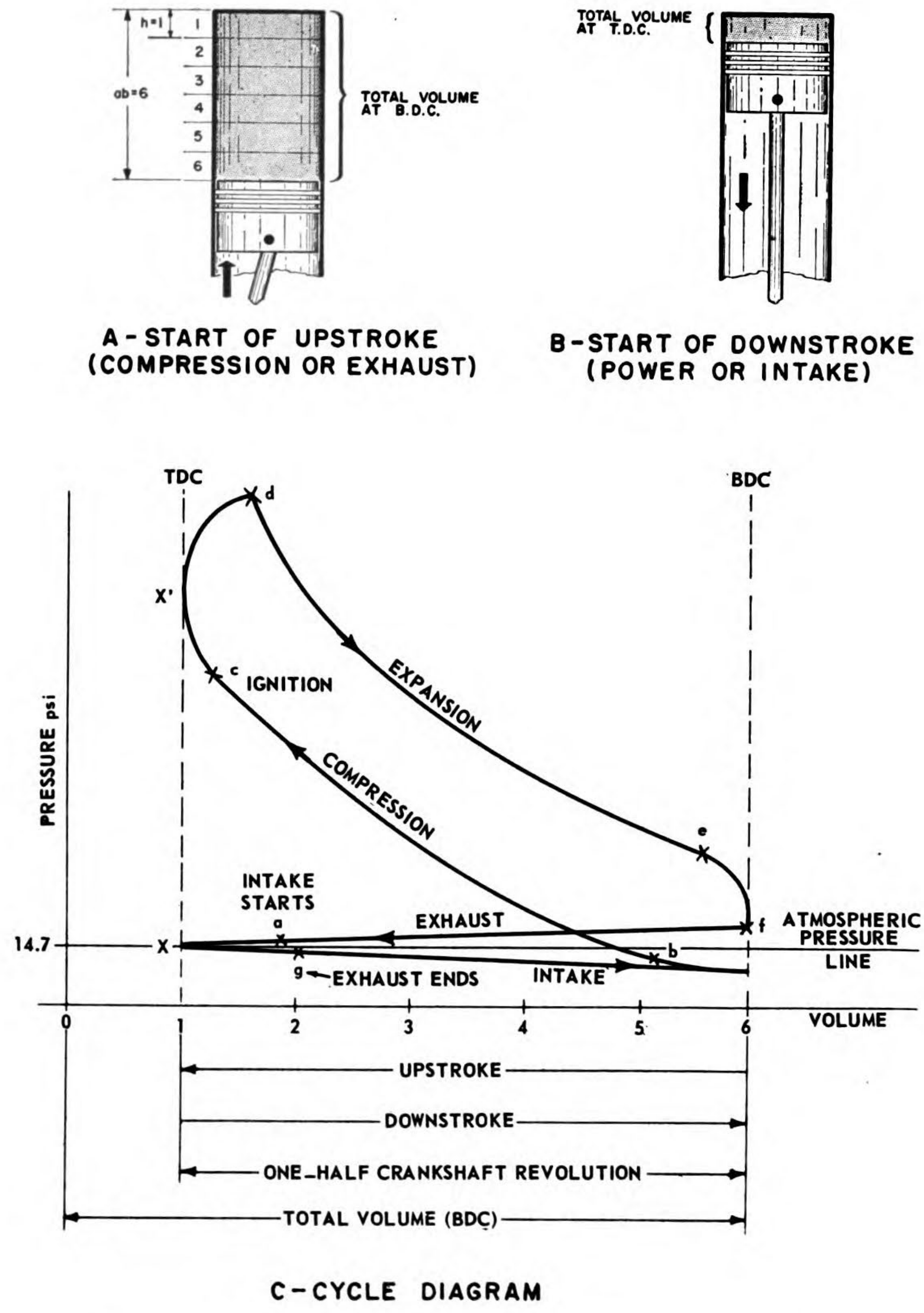


Figure 2–6.—Pressure-volume diagram, Otto 4-stroke cycle.

pace with the change in volume caused by piston travel; thus combustion is said to occur at CONSTANT PRESSURE (represented by line BC).

MODIFIED COMBUSTION CYCLES.—The preceding discussion covers the theoretical combustion cycles which serve as the basis for modern engines. In actual operation, modern engines operate on modifications of the theoretical cycles. However, characteristics of the true cycles are incorporated in the cycles of modern engines. This is pointed out in the following discussion of examples representing the actual cycles of operation in gasoline and Diesel engines.

The following examples are based on the 4-stroke mechanical cycle since the majority of gasoline engines use this type cycle; thus, a means of comparing the cycles found in both gasoline and Diesel engines is provided. Differences existing in Diesel engines operating on the 2-stroke cycle are pointed out.

The illustrations in figures 2–6 and 2–7 are representative of the changing conditions in a cylinder during engine operation. Some of the events are exaggerated in order to show more clearly the change which takes place and, at the same time, to show how the theoretical and actual cycles differ.

The compression ratio situation and a pressure-volume diagram for a 4-STROKE OTTO CYCLE is shown in figure 2–6. Illustration A shows the piston on BDC at the start of an upstroke. (In a 4-stroke cycle engine, this stroke could be either that identified as the compression stroke or the exhaust stroke.) Notice that in moving from BDC to TDC (illustration B), the piston travels 5/6 of the total distance *ab*. In other words, the VOLUME has been decreased to 1/6 of the volume when the piston was at BDC. Thus, the compression ratio is 6 to 1.

Illustration C shows the changes in volume and pressure during one complete 4-stroke cycle. Note that the lines representing the combustion and exhaust phases are

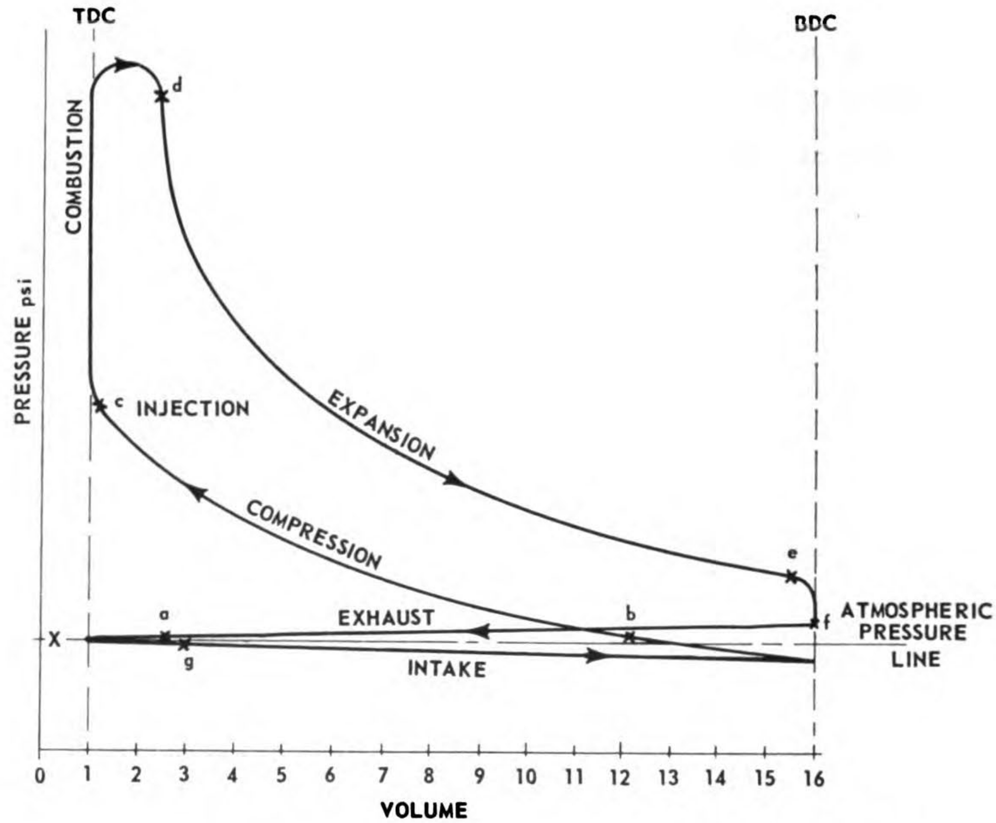


Figure 2–7.—Pressure-volume diagram, modified Diesel 4-stroke cycle.

not straight as they were in the theoretical diagram. As in the diagram of the theoretical cycle, the vertical line at the left represents cylinder pressure in psi. Atmospheric pressure is represented by a horizontal line called the ATMOSPHERIC PRESSURE LINE. Pressures below this line are less than atmospheric pressures, while pressures above the line represent compression. The bottom horizontal line provides a means of representing cylinder volume and piston movement. The volume line has been divided into six parts which correspond to the divisions of volume shown in illustration A. Since piston movement and volume are proportional, the distance between 0 and 6 indicates the volume when the piston is at BDC, and the distance from 0 to 1 the volume with the piston at TDC. Thus, the distance from 1 to 6 corresponds to total piston travel and units of the distance may be used to identify

changes in volume resulting from the reciprocating motion of the piston.

The curved lines of illustration C represent the changes of both pressure and volume which take place during the four piston strokes of the cycle. To conform to the discussion on the relationship of strokes and events (see fig. 2–1), the cycle of operation starts with intake. In the case of the Otto cycle, this event includes the admission of fuel and air. As indicated earlier, the intake event starts before TDC, or at point *a*, illustration C. Note that pressure is decreasing and after the piston reaches TDC and starts down, a vacuum is created which facilitates the flow of the fuel-air mixture into the cylinder. The intake event continues a few degrees past BDC, ending at point *b*. Since the piston is now on an upstroke, compression takes place and continues until the piston reaches TDC. Note the increase in pressure (x *to* x') and the decrease in volume (f *to* x). Spark ignition at *c* starts combustion which takes place very rapidly. There is some change in volume since the phase starts before and ends after TDC.

There is a sharp increase in pressure during the combustion phase. The relative amount is shown by the curve *cd*. The increase in pressure provides the force necessary to drive the piston down again. The gases continue to expand as the piston moves toward BDC, and the pressure decreases as the volume increases, from *d to e*. The exhaust event starts a few degrees before BDC, at *e*, and the pressure drops rapidly until the piston reaches BDC. As the piston moves toward TDC, there is a slight drop in pressure as the waste gases are discharged. The exhaust event continues a few degrees past TDC to point *g* so that the incoming charge aids in removing the remaining waste gases.

The MODIFIED DIESEL COMBUSTION CYCLE, sometimes called the semi-Diesel cycle, is one in which the combustion phase, induced by compression ignition, begins on a constant-volume basis and ends on a constant–pressure basis.

In other words, the modified cycle is a combination of the Otto and true Diesel cycles. The modified cycle is used as the basis for the design of practically all modern Diesel engines.

An example of a pressure-volume diagram for a modified 4-stroke Diesel engine is shown in figure 2–7. Note that the volume line is divided into 16 units, indicating a 16 to 1 compression ratio. The higher compression ratio accounts for the increased temperature necessary to ignite the charge. By comparing this illustration with illustration C of figure 2–6, you will find the phases of the Diesel cycle are relatively the same as those of the Otto cycle, except for the combustion phase. Fuel is injected at point *c* and combustion is represented by line *cd*. While combustion in the Otto cycle is practically at constant-volume throughout the phase, combustion in the modified Diesel cycle takes place with volume practically constant for a short time, during which period there is a sharp increase in pressure, until the piston reaches a point slightly past TDC. Then, combustion continues at a relatively constant pressure, dropping slightly as combustion ends at *d*. For these reasons, the combustion cycle in modern Diesel engines is sometimes referred to as the CONSTANT-VOLUME CONSTANT-PRESSURE cycle.

Pressure-volume diagrams for gasoline and Diesel engines operating on the 2-stroke cycle would be similar to those just discussed, except that separate exhaust and intake curves would not exist. They do not exist because intake and exhaust occur during a relatively short interval of time near BDC and do not involve full strokes of the piston as in the case of the 4-stroke cycle. Thus, a pressure-volume diagram for a 2-stroke modified Diesel cycle would be similar to a diagram formed by *f-b-c-d-e-f* of figure 2-7. The exhaust and intake phases would take place between *e* and *b* with some overlap of the events. (See fig. 2–2.)

The preceding discussion has pointed out some of the main differences between engines which operate on the

Otto cycle and those which operate on the modified Diesel cycle. In brief, these differences involve (1) the mixing of fuel and air, (2) compression ratio, (3) ignition, and (4) the combustion process.

Reference to differences in engines brings up another variation which may be found in the engines which you may operate and maintain. That is the manner in which the pressure of combustion gases acts upon the piston to move it in the cylinder of an engine. The way gas pressure acts upon a piston is sometimes used as a method of classifying engines.

Engines Classified According to the Action of Pressure on Pistons

Engines are classified in many ways. You are already familiar with some classifications such as those based on (1) the fuels used (Diesel fuel and gasoline), (2) the ignition methods (spark and compression), (3) the combustion cycles (Otto and Diesel), and (4) the mechanical cycles (2-stroke and 4-stroke). Additional information is given in subsequent chapters of this course on some of the factors related to the above classifications as well as to other classifications, such as those based on the cylinder arrangements (V, in-line, opposed, etc.), the cooling media (liquid and air), and the valve arrangements (L-head, valve-in head, etc.).

The classification of engines according to combustion-gas action is based upon a consideration of whether the pressure created by the combustion gases acts upon one or two surfaces of a single piston or against single surfaces of two separate and opposed pistons. The three types of engines under this classification are commonly referred to as SINGLE-ACTING, OPPOSED-PISTON, and DOUBLE-ACTING ENGINES.

SINGLE-ACTING ENGINES.—Engines of this type are those which have one piston per cylinder and in which the pressure of combustion gases acts only on one surface of the piston. This is a feature of design rather than

principle, for the basic principles of operation apply whether an engine is single-acting, opposed-piston, or double-acting.

The pistons in most single-acting engines are of the trunk type (length greater than diameter). The barrel or wall of a piston of this type has one end closed (crown) and one end open (skirt end). Only the crown of a trunk piston serves as part of the combustion space surface. Therefore, the pressure of combustion can act only against the crown; thus, with respect to the surfaces of a piston, pressure is SINGLE-ACTING.

Most reciprocating internal combustion engines are of the single-acting type. The engines described and illustrated in *Fireman,* NavPers 10520–A, are of this type. All 4-stroke cycle engines and many 2-stroke cycle engines are single acting. Since this is the case, you will find that most modern gasoline engines as well as many of the Diesel engines used by the Navy are single-acting.

OPPOSED-PISTON ENGINES.—Engines of this type are not to be confused with engines of the "flat" or 180° V-type. Flat engines have two rows of cylinders in a horizontal plane with one crankshaft located between the rows and serving both rows of cylinders. Engines of this design are of single-acting type and are sometimes referred to as horizontal-opposed engines (the term is based on cylinder arrangement). With respect to combustion-gas action, the term OPPOSED-PISTON is used to identify those engines which have TWO PISTONS and ONE COMBUSTION SPACE in each cylinder. The pistons are arranged in "opposed" positions; that is, crown to crown, with the combustion space in between. (See fig. 2–8.) When combustion takes place, the gases act against the crowns of both pistons, driving them in opposite directions. Thus, the term "opposed" not only signifies that, with respect to pressure and piston surfaces, the gases act in "opposite" directions, but also classifies piston arrangement within the cylinder.

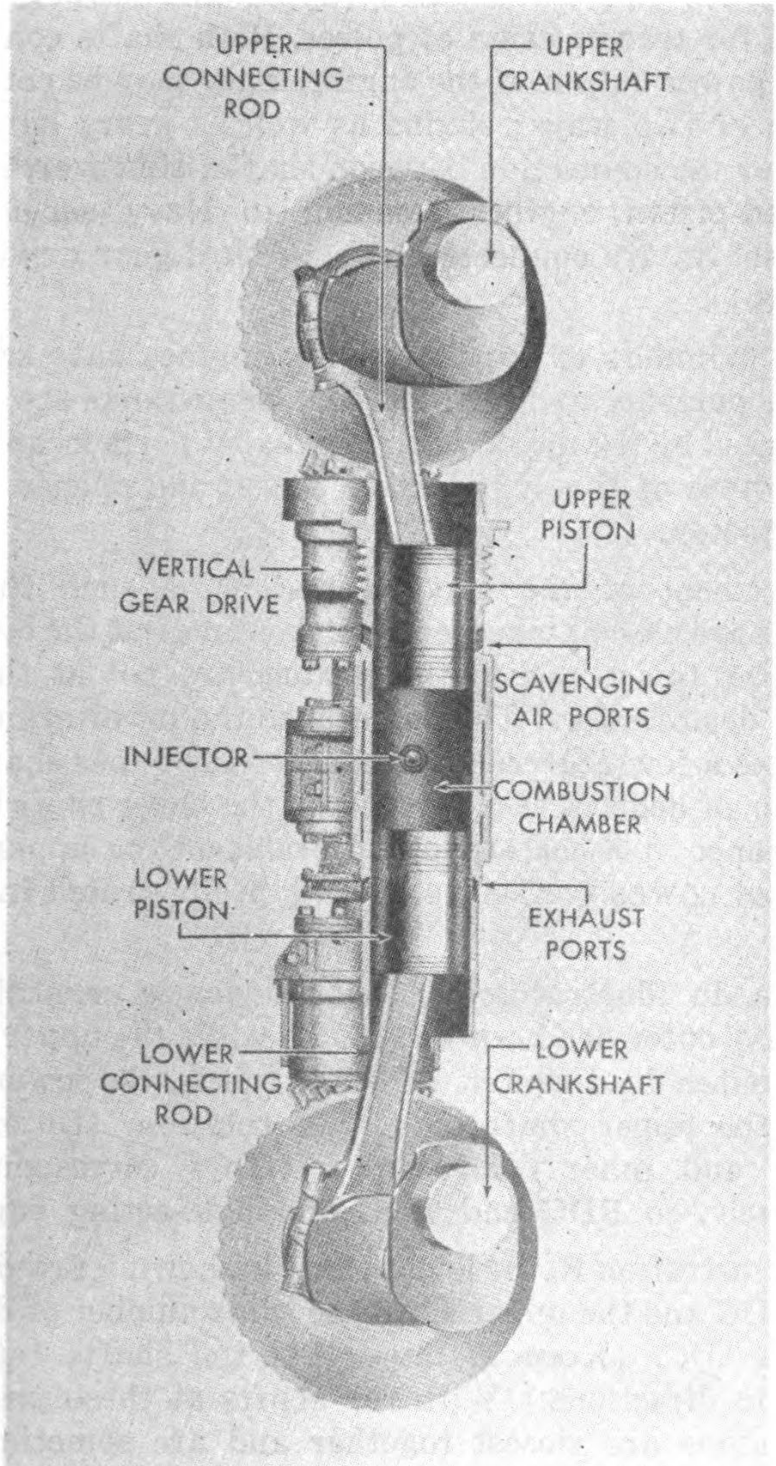


Figure 2–8.—Cylinder and related parts—opposed-piston engine.

In modern engines which have the opposed-piston arrangement, two crankshafts (upper and lower) are required for transmission of power. Both shafts contribute to the power output of the engine. They may be connected in one of two ways; chains as well as gears have been used for the connection between shafts. However, in most opposed-piston engines common to Navy service, the crankshafts are connected by a vertical gear drive. (See fig. 2–8.)

The cylinders of opposed-piston engines have scavenging air ports located near the top. These ports are opened and closed by the upper piston. Exhaust ports located near the bottom of the cylinder are closed and opened by the lower piston.

Movement of the opposed pistons is such that the crowns are closest together near the center of the cylinder. When at this position, the pistons are not at the true piston dead centers. This is because the lower crankshaft operates a few degrees in advance of the upper shaft. The number of degrees that a crank on the lower shaft travels in advance of a corresponding crank on the upper shaft is called LOWER CRANK LEAD. This is illustrated in figure 2–9.

Note, in illustration A, that the lower crankshaft is 12° PAST outer dead center (ODC) while the upper piston is ON outer dead center. In other words, the lower shaft leads the upper shaft by 12° of rotation. (Outer dead center and inner dead center (IDC) correspond, respectively, to BDC and TDC of single-acting engines.)

In illustration B, the lower shaft is shown a few degrees PAST IDC and the upper shaft the same number of degrees BEFORE IDC. (Keep in mind that the shafts rotate in opposite directions.) With the shafts at these positions, the pistons are closest together and are sometimes referred to as being at COMBUSTION DEAD CENTER. Note that the midpoint between the shaft positions is piston dead center.

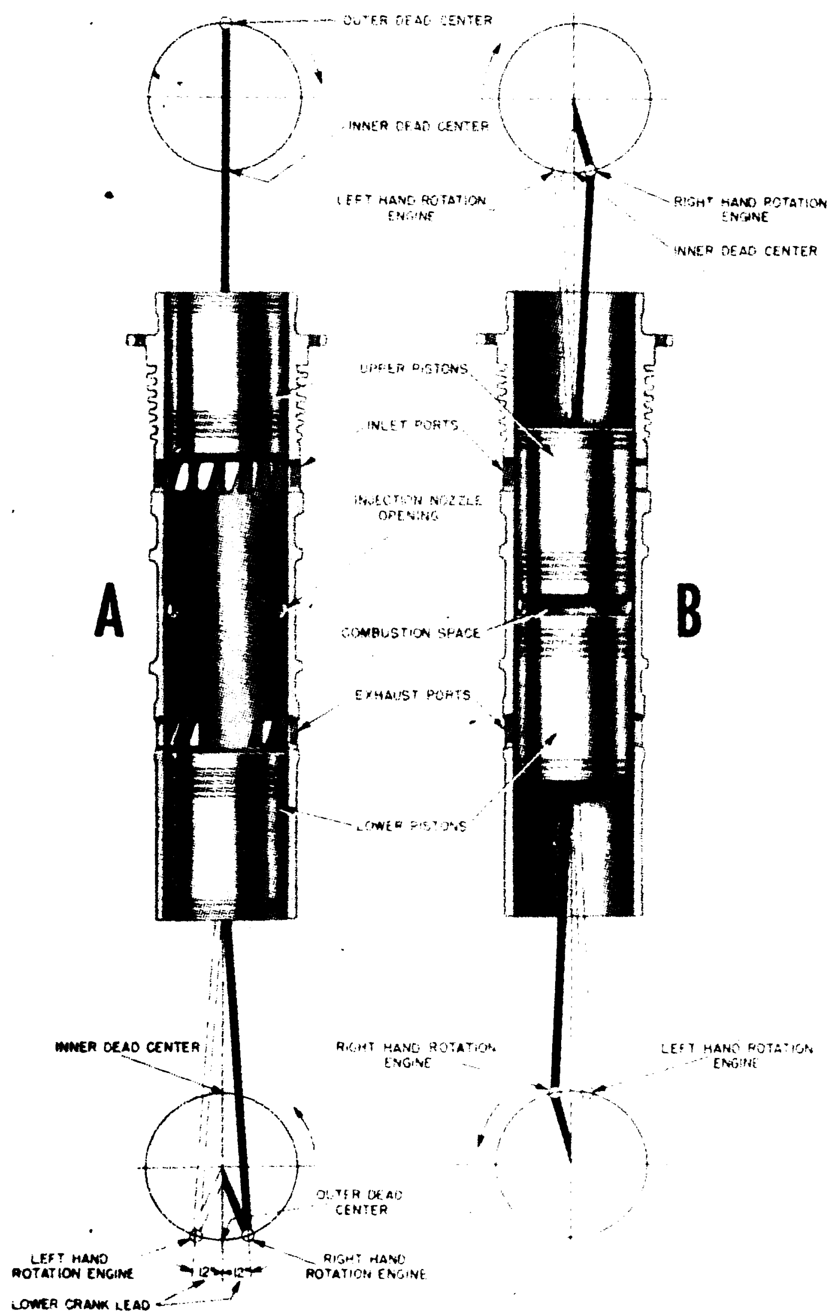


Figure 2–9.—Lower crank lead, opposed-piston engine.

Opposed-piston engines used by the Navy operate on the 2-stroke cycle. In engines of the opposed-piston type, as in 2-stroke cycle single-acting engines, there is an overlap of the various events occurring during a cycle of operation. Injection and the burning of the fuel start during the latter part of the compression event and extend into the power phase. There is also an overlap of the exhaust and scavenging periods. The events in the cycle of operation of an opposed-piston, 2-stroke Diesel cycle engine are shown in figure 2–10.

In illustration (1), the cylinder is charged with air and the pistons are moving toward IDC. Since the scavenging air ports are covered by the upper piston and the exhaust ports are covered by the lower piston, compression is taking place. A few degrees before the lower piston reaches IDC, fuel is injected (2) and combustion occurs. Injection is completed (3) slightly before the pistons reach combustion dead center, where compression is highest. The combustion of the fuel almost doubles the pressure shortly after this point in the cycle. As the gases expand (4), the pistons are driven in opposite directions toward the outer dead centers and power is transmitted to both crankshafts. As the pistons approach ODC, the lower piston uncovers the exhaust ports and most of the waste gases escape. This is followed by the upper piston uncovering the scavenging air ports (5). The scavenging air forces the remaining gases out of the cylinder. Then, the lower piston covers the exhaust ports (6) and air continues to fill the cylinder until the upper piston covers the scavenging air ports, thus completing the cycle.

In the cycle of operation just described, the exhaust ports are uncovered (5) and covered (6) slightly before the intake ports are opened and closed because of the lower crankshaft lead. Lower crank lead influences scavenging as well as power output.

Since the intake ports are open for a brief interval after the exhaust ports close, air can be forced into the

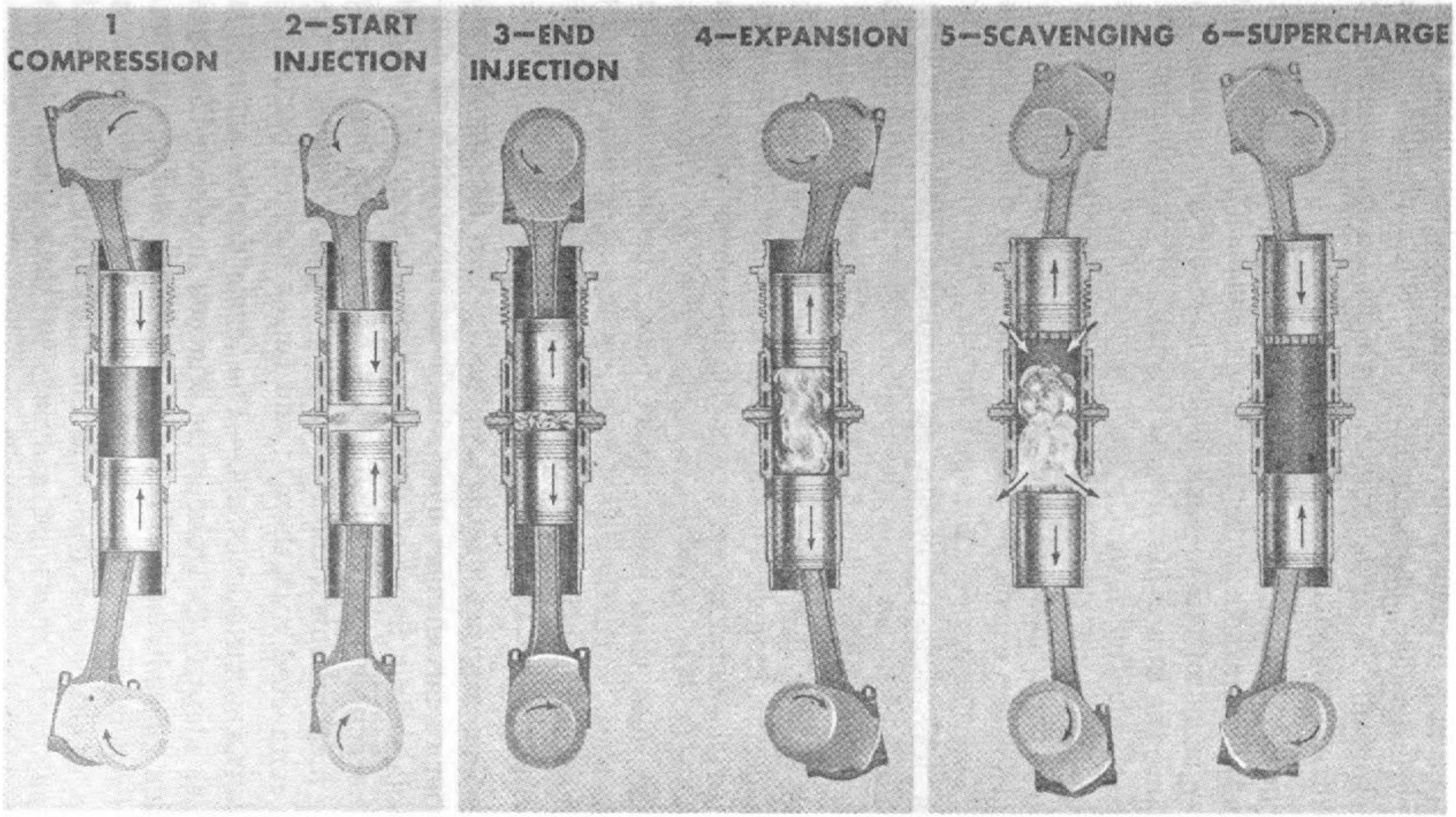


Figure 2—10.—Events in operating cycle of an opposed-piston engine.

cylinder at a pressure above that of the atmosphere (i.e., the cylinder can be supercharged). This results in the development of more power than would be possible if pressure were normal.

Crank lead also results in less power being delivered to the upper shaft than to the lower shaft. The amount of power transmitted to each crankshaft differs because by the time the upper piston reaches IDC after injection and combustion, the lower piston has already entered the power phase of the cycle. The lower piston, therefore, receives the greater part of the force created by combustion. In other words, by the time the upper piston reaches IDC and begins to transmit power, the volume of the gases has already begun to increase. Therefore, the pressure acting on the upper piston is less than that acting on the lower piston when it began to deliver power.

The power delivered by the lower crankshaft varies with engine models. In some engines, from 70 to 80 percent of the total power output is delivered by the lower crankshaft. The power available from the upper shaft, already less than lower shaft power because of lower crank lead, is further reduced, insofar as engine output is concerned, by the load of the engine accessories which the upper shaft generally drives.

Modern engines of the opposed-piston design have a number of advantages over single-acting engines of comparable rating. Some of these advantages are: less weight per horsepower developed; lack of cylinder heads and valve mechanisms (and the cooling and lubricating problems connected with them) ; and fewer moving parts.

DOUBLE-ACTING ENGINES.—The term "double-acting" is used to identify 2-stroke cycle engines in which the combustion gases in a cylinder act, first, on one end of a piston, and then on the other. In order that the gases act on a piston in this order, the design of the engine cylinder and related parts must be similar to that illustrated in figure 2–11.

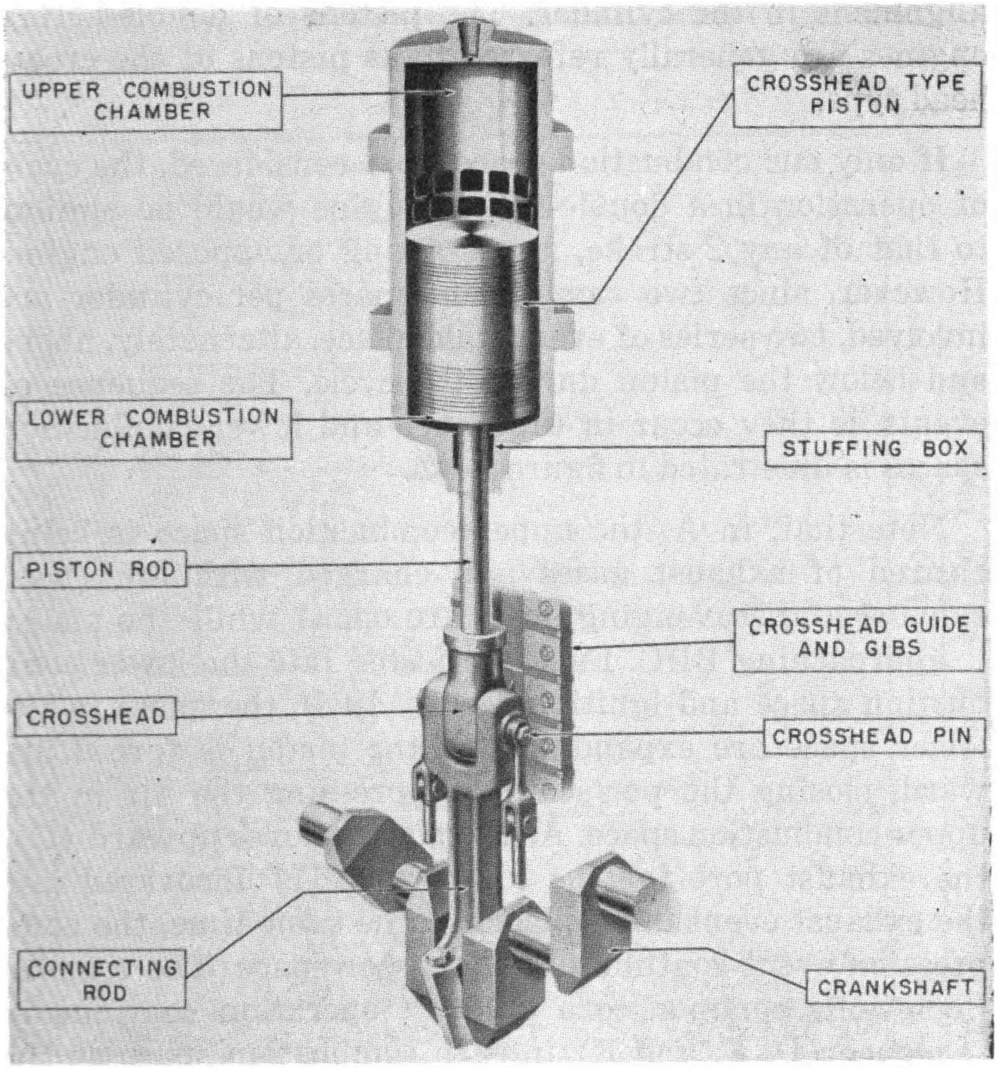


Figure 2–11.—Cylinder and related parts for a double-acting engine.

The pistons in a double-acting engine are usually shorter than the trunk-type pistons common to single-acting and opposed-piston engines. Since combustion takes place in both ends of the cylinder, the cylinder must be sealed and both ends of the piston closed. A piston rod, fastened to the lower end of the piston, extends through a stuffing box in the lower cylinder head. The lower end of the rod is connected to a crosshead which is attached, by a pin, to the connecting rod. As the engine operates, the flat bearing surface on the crosshead moves up and down in a crosshead guide, keeping the piston and rod in proper

alignment in the cylinder. The pistons of double-acting engines are generally referred to as pistons of the cross-head type.

If only one combustion space were considered, the cycle of operation in a double-acting engine would be similar to that of any 2-stroke, single-acting or opposed engine. However, since two combustion spaces per cylinder are involved, two series of events take place, alternately, above and below the piston during the cycle. The sequence of events as they occur in the upper and lower combustion spaces is illustrated in figure 2–12.

Note that, in A, the upper combustion space is being cleared of exhaust gases and charged with air (both exhaust and scavenging ports are open) while the piston is approaching BDC. Fuel is injected into the lower combustion space and ignition occurs. In B, the gases in the lower space are expanding and the piston is forced upward, closing the ports and compressing the air in the upper combustion space. As the piston moves upward (C), the exhaust port for the lower space is uncovered and the exhaust event takes place. At the same time, the compression event continues in the upper space. The remaining events common to a cycle of operation continue in sequence (D, E, and F) in each combustion space as the piston moves to TDC and then down. Note that conditions illustrated in D, E, and F are just the reverse of those shown in A, B, and C. In other words, as injection, ignition, expansion, and exhaust take place in the upper combustion space, scavenging and compression take place in the lower space.

A review of the preceding discussion will reveal that there is a power impulse for each stroke of the piston (see B and E of figure 2–12). For this reason, the 2-stroke cycle, double-acting engine has a greater power output than a comparable engine of the single-acting type. Double-acting engines operate more smoothly than single-acting engines because compression in one end of the

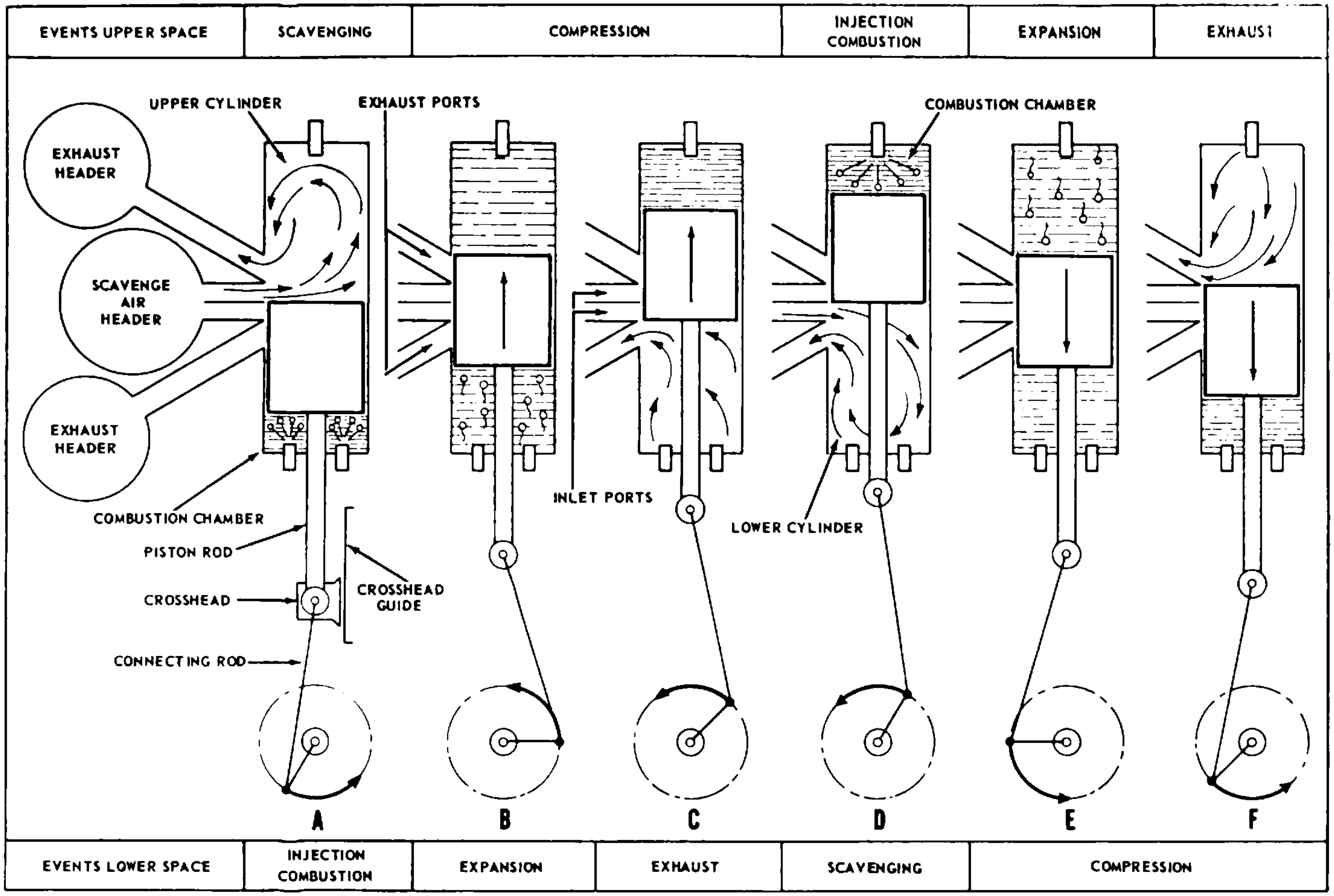


Figure 2—12.—Operating cycle of a double-acting, 2-stroke cycle, Diesel engine.

cylinder "cushions" the power impulse occurring in the opposite combustion space.

Even though double-acting engines have a number of advantages over comparable engines of other types, they have some disadvantages in marine applications in the Navy. Double-acting engines are more costly to operate because they require nearly twice as much fuel per cycle as single-acting engines but do not deliver twice as much power. Also, double-acting engines are somewhat complicated and cumbersome in design. Because of the design and construction of the crosshead-type pistons and related parts, double-acting engines are considerably larger and more bulky than single-acting engines. Also, many difficulties have been encountered in maintaining a gas-tight seal at the stuffing box where the piston rod passes through the lower cylinder head. For reasons such as those just pointed out, many double-acting engines have been replaced with 2-stroke cycle, single-acting engines. When compared to the number of engines of other types now in use, double-acting engines are definitely in the minority.

GAS TURBINE INTERNAL COMBUSTION ENGINES

Until recently, the application of the gas turbine engine to marine use in the Navy has been experimental. Experiments have proved that the gas turbine engine can be advantageously used to power short-range vessels, landing craft, high speed craft such as PT and Air-Sea Rescue boats, emergency generators, and portable fire-fighting equipment. The first United States Naval vessels to use gas turbine engines on an operational basis were the MSB–5 class minesweepers. Gas turbine installations aboard these vessels supply motive power for the generators in minesweeping operations. Two gas turbine engines drive the generator through a combining reduction gear. The output shafts of the engines are connected to the combining reduction gear by flexible couplings and overrunning clutches. The engines for this unit are manu-

factured by Boeing and the generator is a General Electric product.

Other applications of the gas turbine engine are to be made on an operational basis and the number of gas turbines in service will probably increase considerably as service experience is gained. Since both the number of installations and service experiences are limited at present, the following discussion deals principally with a comparison of gas turbines and reciprocating engines, the advantages and disadvantages of the gas turbine as a power plant, and the terminology and operating principles of gas turbine engines and their principal component parts.

Comparison of Gas Turbines and Reciprocating Engines

The gas turbine resembles internal combustion engines of the reciprocating type in that air is compressed, a fuel-air mixture is burned, and the gases of combustion are expanded to produce useful power. As you know, engines of the reciprocating type use one structure, the cylinder, for compression, combustion, and expansion. Since all three phases do take place within one unit, the power impulse must occur intermittently as the cycle is repeated. This is not the case in gas turbine engines. Instead, compression, combustion, and the expansion take place in three separate components. Air is compressed in one unit, combustion takes place in an adjacent burner, and a turbine (or turbines) receives the force created by combustion. As in the case of the piston in a reciprocating engine, the turbine transmits the force of the gases to a shaft which drives a useful load. The three basic units of the gas turbine engine are so arranged and connected that the power output from the turbine is steady and continuous. In addition to the development of a uniform flow of power output, engines of the gas turbine type have several advantages over the conventional internal combustion engine of the reciprocating type.

Advantages and Disadvantages of Gas Turbine Engines

The advantages and disadvantages of the gas turbine engine cannot be listed in order of importance, because the requirements of the engine as a source of power differ in various vessels and applications. Not all of the desirable or undesirable features of gas turbine engines are discussed here; however, some of the more important ones are pointed out.

Compared to other types of internal combustion engines, the gas turbine engine weighs less, takes up less space, and has the simpler design with a far smaller number of moving parts. The gas turbine engine develops more power per unit of weight and unit of volume than another engine. For example, a gasoline engine of a given horsepower weighs approximately six times as much as a gas turbine of the same horsepower and a Diesel engine of that horsepower is almost twelve times as heavy as the gas turbine. The gas turbine occupies less than one-third of a volume of a comparable gasoline engine and approximately one-fifth of the volume of a comparable Diesel.

Gas turbine engines start quickly and accelerate rapidly. Some models can develop full power from a cold start in less than one-tenth of the time required for a gasoline engine in a comparable application. The gas turbine adjusts to varying loads more rapidly than other type engines.

The number of personnel required to operate and maintain a gas turbine engine and the time required for the training of such personnel are much less than in the case of engines of other types. In some cases, only one man is needed for starting and operating a gas turbine engine. The simplicity of the operating controls and the automatic safety devices employed reduce the time required for training operators. The time required for training maintenance personnel is much less than that required in the case of other engines because of the simplicity of design and the smaller number of moving parts in the gas turbine.

Compared to a Diesel engine, the gas turbine has far fewer components, produces much less vibration at full power, and uses practically no lubricating oil. (The Diesel engine uses approximately 40 times as much lube oil as the gas turbine engine.)

The gas turbine engine has a significant advantage over the gasoline engine in the fuel used. The distillate fuel used in gas turbines presents much less of a fire hazard than the highly volatile fuel used in gasoline engines.

Even though the gas turbine engine has some advantages over other types of internal combustion engines, it also has some disadvantages such as a higher rate of fuel consumption and larger components required for air inlet and exhaust. Service experience may reveal still other disadvantages.

A Two-Stage Turbine Engine and Its Parts

As a "heat" engine, the gas turbine engine employs processes in its operation which are similar to those employed in other types of internal combustion engines. Even so, the engine parts and the terms used to identify them are considerably different from the parts and terms which are common to Diesel and gasoline engines. The terms defined here and the operating principles and components discussed later are applicable to Boeing 502 engines. Even though gas turbine engines vary in design and even though future installations may include engines of other manufacturers, much of the discussion in the following section will still be applicable.

GAS TURBINE ENGINE.—*An internal combustion engine that produces power by a continuous and self-sustaining process.* An air mass is compressed and is then united with atomized fuel. The resulting combustible mixture then burns. The gases of combustion expand through one or more turbines which convert some of the energy into useful power.

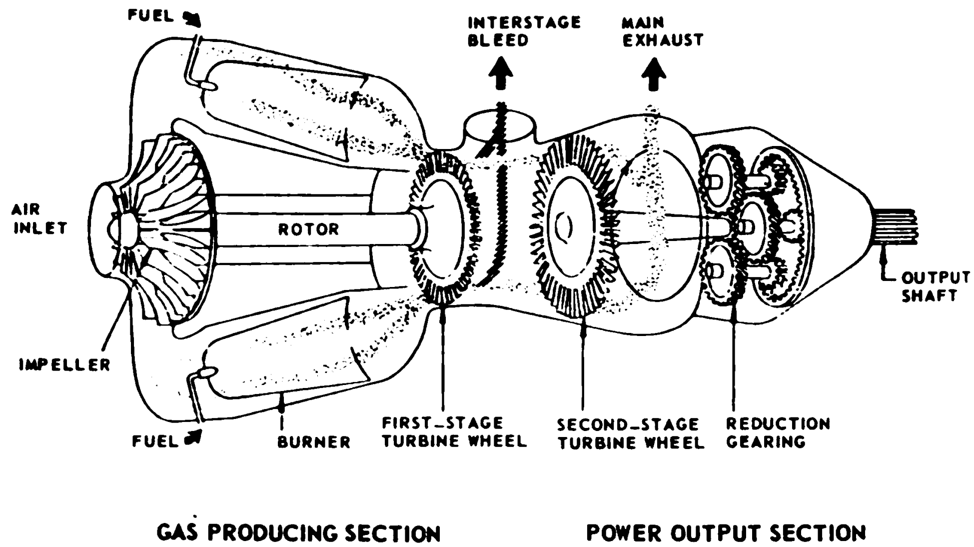


Figure 2–13.—Schematic illustration of a 2-stage gas turbine (Boeing 502).

A Boeing 502 engine is divided into two sections or STAGES. (See fig. 2–13.)

FIRST STAGE.—*The forward (compressor end) section of the engine where a stream of expanding gases is created as a result of continuous combustion.* This section consists principally of the compressor, burners, and rotor. This group of parts is referred to as the gas producing section.

SECOND STAGE.—*The rear (output shaft end) section of the engine which converts the energy of the gas stream into useful power.* This section is referred to as the power producing section; its main parts are the turbine wheel, exhaust ducts, reduction gear, and output shaft.

COMPRESSOR.—*That part of the engine which draws in air and compresses it by centrifugal force.* The compressor consists of a rotating IMPELLER (a vaned disk) enclosed by a case which has diffusing vanes on its inner surface.

BURNER.—*That part of the engine in which combustion occurs.* It consists of a cylindrical outer shell, perforated inner liner, fuel nozzle, and igniter plug.

NOZZLE BOX.—*A metal chamber that collects combustion gases from the burners and directs them through fixed vanes or nozzles against a turbine wheel.*

TURBINE WHEEL.—*A bladed disc which rotates when the gas stream acts upon its blades.*

ROTOR.—*A rotating assembly consisting of the compressor impeller, an interconnecting shaft, and a turbine wheel.*

INTERSTAGE BLEED ASSEMBLY.—*A circular metal duct, containing a ring of fixed vanes that form nozzles.* These nozzles direct the gas flow from the first-stage turbine to the second-stage turbine. This assembly also provides a means of releasing some of the combustion gases to the exhaust ducting ahead of the second-stage turbine.

WASTE GATE.—*A gate type valve in the interstage bleed duct that controls the escape of combustion gases ahead of the second-stage turbine.*

EXHAUST DAMPER.—*A gate type valve in the turbine exhaust duct that controls the escape of gases aft of the second-stage turbine.*

Operating Principles of a Two-Stage Gas Turbine Engine

In a two-stage gas turbine engine, the gases of continuous combustion are discharged through the two turbine wheels. The first turbine furnishes power for the impeller of the compressor and the other turbine drives the output shaft through a reduction gear. Even though both rotating elements of the engine are mounted on a common base, each turbine wheel is mechanically independent of the other. An interconnecting duct confines the gas flow between the two stages of the engine.

The principal parts of a 2-stage gas turbine are illustrated in figure 2–13. The path of gas, from intake to exhaust, is also shown. Make frequent reference to figure 2–13 as you study the operating principles of a 2-stage gas turbine.

Air enters the compressor through an inlet bell. The pressure of the air mass is increased more than three times by the blades of the rotating impeller. After compression, the air is discharged at high velocity into two burners. Atomized fuel is sprayed into the burners and

the resultant combustible mixture burns at a high temperature (approximately 3500°F for the engine shown). Electrical ignition is necessary only for starting the combustion process. Once started, combustion is self-sustaining throughout the speed range of the engine.

Combustion requires about one-fourth of the air which enters the burners. The air not used for combustion surrounds the flame and protects the metal parts from the high temperatures of steady combustion. Incoming air replaces this "protective" air, forcing it out of the burners and mixing it with the combustion gases. Sufficient heat is absorbed by the air to hold the maximum operating temperature at the exhaust collector below that specified (1225°F for the engine shown).

The combustion gases from the burners mix together in the nozzle box and expand through a ring of fixed vanes. The vanes direct the gases as jets against the blades of the first-stage turbine wheel. Since this wheel is directly connected by shaft to the impeller, continuous compression is provided for engine operation.

The gases leave the first turbine and expand through another ring of fixed vanes which force the gases against the blades of the second turbine wheel. Thus, the energy of combustion is converted into useful power when the second turbine wheel, through reduction gears, drives the output shaft of the engine. After the force of the gases has been expended, the waste gases are exhausted to the atmosphere.

The power developed by a gas turbine engine is primarily dependent upon gas flow, which in turn is governed by the amount of fuel that is burned. In a 2-stage engine, the output shaft speed is regulated by controlling the gas flow through the second turbine wheel.

Smooth control of the power output of a 2-stage gas turbine is possible because the two turbine wheels are mechanically separate; therefore, their speeds are independent. During engine operation, the effect produced by the two turbine wheels is the same as that of a hydraulic

torque converter. Because of this, the second turbine wheel can be stalled while the first turbine wheel continues to operate at rated rpm. This arrangement permits the driven unit to be started and its speed to be changed smoothly.

When a two-stage gas turbine engine is operating under load, the first stage operates steadily at the speed that will produce a sufficient flow of combustion gases to the second stage. Only the gas flow necessary for the required power output passes through the second turbine and main exhaust. Gas in excess of that required is exhausted through the interstage bleed duct.

A waste gate in each of the interstage bleed ducts regulates the amount of gases exhausted through the interstage bleed. The waste gates are operated simultaneously by a hydraulic unit which is controlled by a speed-sensitive centrifugal governor. At maximum load, the waste gates are completely closed and the exhaust damper is wide open; thus, all of the gas flow is directed through the second turbine wheel. Under minimum load conditions, the waste gates are wide open and the exhaust damper is closed sufficiently to restrict the gas flow as necessary to maintain the second turbine wheel rpm within the desired limits. As load on the engine varies, the duct valves (waste gates and exhaust damper) are positioned by the actuating unit to regulate gas flow as required.

Other Gas Turbine Engine Components

The main engine components discussed to this point are by no means all that is necessary to make up a complete engine. As in the case of other types of internal combustion engines, the gas turbine engine includes various accessories and systems.

ACCESSORIES.—The parts which constitute the engine accessory group are driven by the engine rotor or by the output shaft. The rotor-driven accessories include the gear type fuel pump, centrifugal fuel control governor,

and vane type combination pressure-scavenge oil pump. A centrifugal overspeed switch is driven by the output shaft.

SYSTEMS.—The principal systems of a gas turbine engine are those which supply fuel for combustion, oil for lubrication, and electricity for starting the engine and the operation of instruments and warning and safety devices. The accessories listed in the preceding paragraph are usually considered as components of whichever system they affect. For example, the fuel pump and governor are considered parts of the ENGINE FUEL SYSTEM.

The fuel system consists of the following components, in addition to the pump and governor: a high-pressure filter, nozzle shutoff valve, pressure gage, starting fuel bypass valve, starting fuel bleed orifice, and two fuel nozzles. The parts of the system and the path of the fuel through the system are schematically illustrated in figure 2–14.

In brief, the fuel flows through the system as follows: the engine-driven fuel pump receives filtered fuel from a motor-driven supply pump, increases the pressure, and then forces the fuel through the high-pressure filter to the governor. The governor meters the fuel to the nozzles

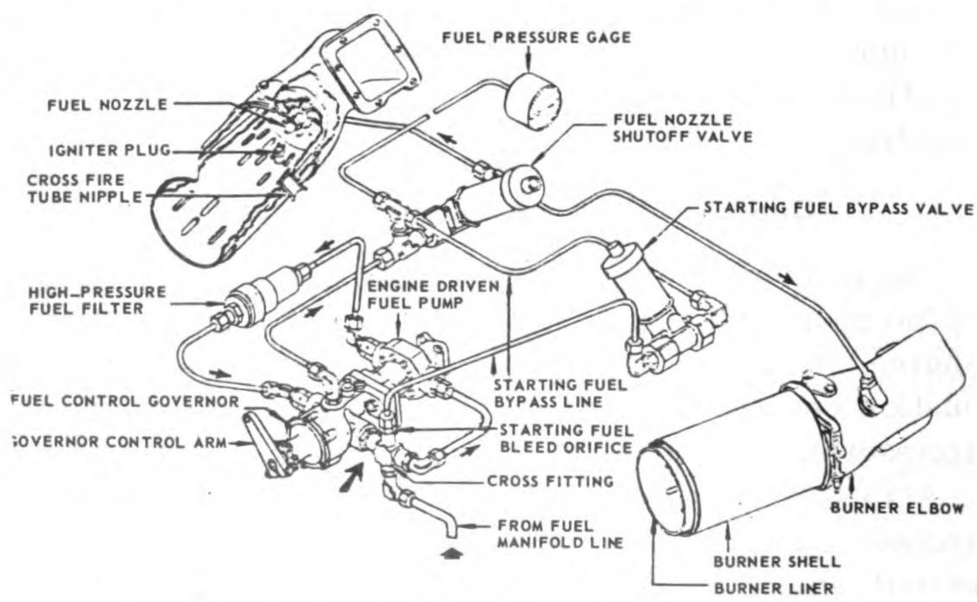


Figure 2—14.—Gas turbine engine fuel system—Boeing 502.

in the amount necessary to maintain combustion at the required rate, and returns any excess fuel to the inlet port of the engine-driven pump.

The fuel nozzle shutoff valve is installed in the line between the governor and the fuel nozzles. The fuel-pressure gage, mounted on the engine control panel, is connected to the line between the governor outlet and the shutoff valve. When the engine is being cranked, fuel nozzle pressure is maintained within a specified range by bleeding excess pressure from the governor outlet line

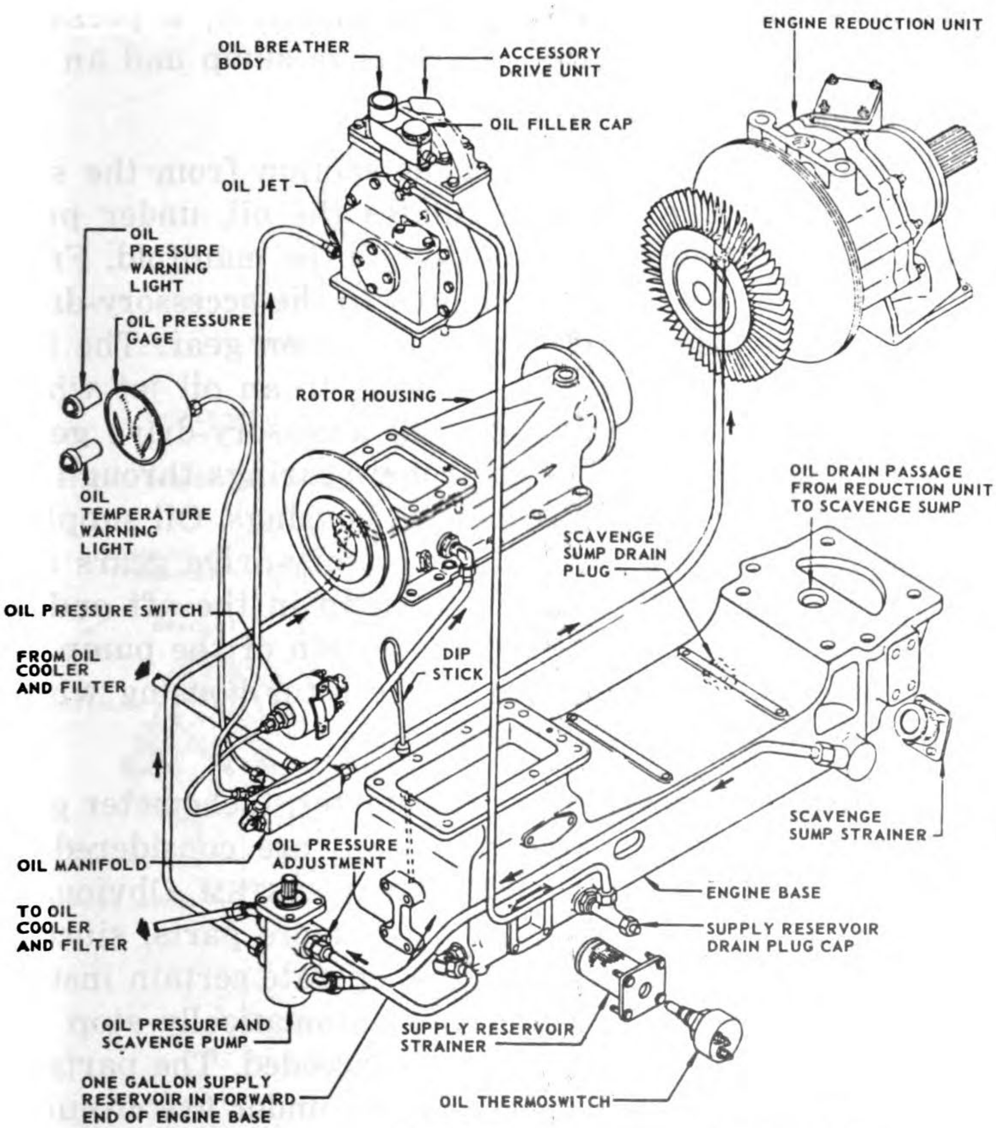


Figure 2–15.—Gas turbine engine oil system—Boeing 502.

to the inlet port of the engine-driven fuel pump. The starting fuel-bypass valve opens the governor outlet line, which contains the starting fuel-bleed orifice. The size of the orifice determines the amount of bleed.

Lubrication within Boeing 502 engines is provided by a circulative type ENGINE OIL SYSTEM. The parts which make up this system and the flow of oil through these parts are schematically illustrated in figure 2–15.

Note that, in addition to the oil pump mentioned under rotor-driven accessories, the system includes lines and strainers, an oil thermoswitch, a manifold, a pressure switch, a supply reservoir, a scavenge sump and an external oil cooler and filter.

The lubricating-oil pump takes suction from the supply reservoir. The pump circulates the oil, under pressure, through the cooler and filter to the manifold. From the manifold, the oil is distributed to the accessory-drive unit, rotor housing, and engine reduction gear. The line to the accessory-drive unit connects to an oil jet which provides spray lubrication for all accessory-drive gears and bearings. Oil reaches the rotor bearings through internal passages in their respective housings. Oil supplied to the rotor bearings and the accessory-drive gears and bearings drains into a separate sump in the aft end of the engine base. The scavenging section of the pump returns the oil from the sump to the rotor housing where it drains into the supply reservoir.

Such engine accessories as the starter, tachometer generator, and engine overspeed switch are considered as components of the ENGINE ELECTRICAL SYSTEM. Obviously, the electrical system includes many more parts, since it must function to start the engine, operate certain instruments and warning devices, and automatically stop the engine when operating limits are exceeded. The parts of the electrical system may be grouped under five circuits: starting, ignition, indicating, warning, and safety. The

parts which make up these circuits and their relative position with respect to other engine parts are schematically shown in figure 2–16.

In the case of installed engine-generator units equipped with Boeing 502 engines, the starting and ignition circuits receive power from storage batteries and the warning and safety circuits receive power from the ship's

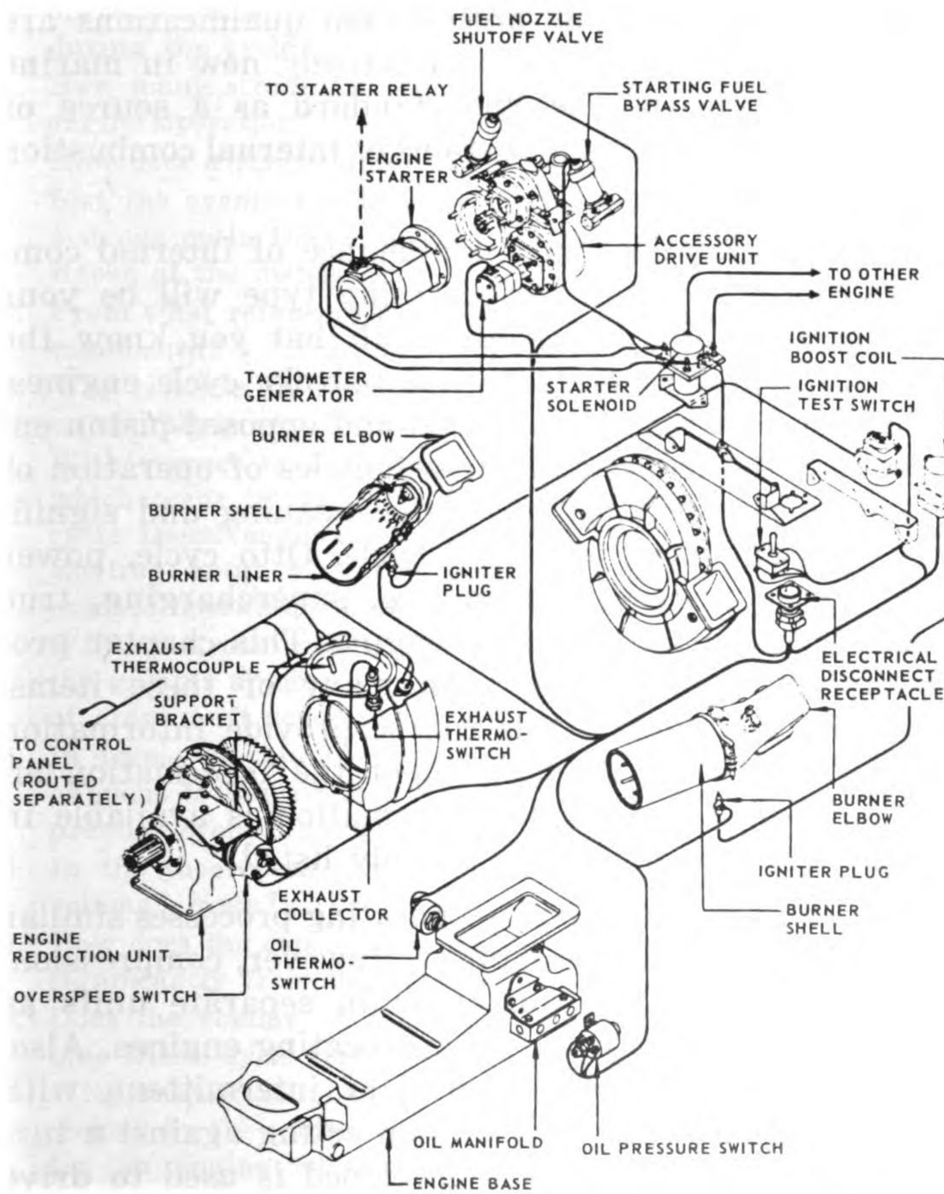


Figure 2–16.—Gas turbine engine electrical system—Boeing 502.

power supply panel. Power for the indicating circuit is self-generated by parts (for example, thermocouple) in the circuits.

SUMMARY

The internal combustion engines used by the Navy are of two principal types—reciprocating and turbine. The first type is the more common and is of primary concern to Enginemen insofar as professional qualifications are concerned. The second type is relatively new in marine applications but may become standard as a source of power in certain Navy applications of internal combustion engines.

Since the operation and maintenance of internal combustion engines of the reciprocating type will be your prime responsibility, it is essential that you know the principles of operation of 2- and 4-stroke cycle engines, single- and double-acting engines, and opposed-piston engines. To fully understand the principles of operation of these engines, you must know the meaning and significance of such terms as Diesel cycle, Otto cycle, power stroke, exhaust stroke, scavenging, supercharging, true Diesel engine, and semi-Diesel engine. This chapter provides information dealing with many of these items. Subsequent chapters in this course provide information which will clarify and supplement the information already presented. Additional information is available in basic courses and references already listed.

Gas turbine engines employ operating processes similar to those of reciprocating engines. However, compression, combustion, and expansion occur in separate units as compared to a single unit in reciprocating engines. Also, combustion is continuous instead of intermittent, with the pressure created by combustion acting against a turbine or turbines. The power developed is used to drive the compressing unit of the engine as well as the output shaft.

QUIZ

1. With respect to engine operation, what does the term "operating cycle" identify?
2. List in proper sequence the events which occur in a cycle of operation of a Diesel engine.
3. In what way do the intake and compression events in the operating cycle of a gasoline engine differ from similar events in the operating cycle of a Diesel engine?
4. Does the number of piston strokes occurring during a cycle of operation determine the number of events which will occur during the cycle?
5. How many strokes of the piston may occur during a cycle of engine operation?
6. How does a stroke differ from an event?
7. List the events which occur during the operating cycle of a 4-stroke cycle Diesel engine that involve more than one full stroke of the piston.
8. From what reference points are the start and end of an event established?
9. Why is there an overlap of the intake and exhaust events of an operating cycle?
10. With respect to TDC and BDC, the majority of the events which occur in the operating cycles of both 2- and 4-stroke cycle Diesel engines start at relatively the same point. The starting point of which event is significantly different in engines operating on these two mechanical cycles?
11. Will a 2-stroke cycle engine or a 4-stroke cycle engine produce the greater number of power impulses during a given number of crankshaft revolutions?
12. In terms of volume–pressure–temperature relationship, what happens to the air in a Diesel engine cylinder while the compression event is taking place?
13. In the theoretical Otto cycle, what does the term "constant volume" mean?
14. How does the combustion phase of the true Diesel cycle differ significantly from that of the Otto cycle?
15. Does the volume of gas during the combustion phase of the true Diesel cycle remain constant, increase, or decrease?
16. With respect to piston motion and gas volume, what is indicated by the combustion curve of a pressure-volume diagram for an engine which operates on the Otto, 4-stroke cycle principle?
17. In what way is the combustion phase of the modified Diesel cycle similar to that of the Otto cycle?

18. A pressure-volume diagram for a 2-stroke cycle engine operating on the modified Diesel cycle does not have separate curves representing the intake and exhaust events as does a diagram for a 4-stroke cycle engine. Why?
19. What is meant by "lower crank lead" in an opposed-piston engine?
20. With respect to crank position, when will the pistons in the cylinder of an opposed-piston engine be closest together?
21. In an opposed-piston engine, do the intake ports or the exhaust ports open first during the operating cycle?
22. In an opposed-piston engine, which crankshaft transmits the greater amount of power to the engine output shaft?
23. What type engine delivers a power impulse to the crankshaft during each stroke of the piston?
24. With respect to processes taking place during the operating cycle, in what way are reciprocating and turbine type internal combustion engines similar?
25. Which event in the operating cycle of a reciprocating type engine does not occur in an operating gas turbine?
26. What is used as a cooling medium in a gas turbine engine?
27. Upon what is the power developed by a gas turbine engine primarily dependent?

CHAPTER 3

PRINCIPAL STATIONARY PARTS OF AN ENGINE

The construction of most internal combustion engines of the reciprocating type follows much the same general pattern. Though engines are not all exactly alike, there are certain features common to all, and the MAIN PARTS of most engines are similarly arranged. Since the general structure of gasoline engines is basically the same as that of Diesel engines, the description of the engine parts and systems given in this chapter and those to follow apply generally to both types of engines. However, differences do exist and these will be pointed out wherever applicable. Since the main difference in Diesel and gasoline engines exists in the fuel systems and the methods of ignition, these subjects are covered in separate chapters.

The main parts of an engine, excluding accessories and systems, may be divided into two principal groups. One group includes those parts which, with respect to engine operation, do not involve motion; namely, the structural frame and its components and related parts. The other group includes those parts which involve motion. This chapter deals principally with the main stationary parts of an engine. Information dealing with the moving parts of an engine is given in the chapters which follow.

The main purpose of the stationary parts of an engine is to maintain the moving parts in their proper relative

position. This is necessary if the gas pressure produced by combustion is to fulfill its function—"push" the pistons and rotate the crankshaft. The prime requirements for the stationary parts of marine engines are: ample strength, low weight, minimum size, and simplicity of design. Strength is necessary if the parts are to withstand the extreme forces developed in an engine; space limitations aboard ship make minimum weight and size essential; while simplicity of design is of great importance when maintenance and overhaul are involved.

ENGINE FRAMES

The term "frame" is sometimes used to identify a single part of an engine; in other cases, it identifies several stationary parts fastened together to support most of the moving engine parts and engine accessories. For the purpose of this discussion, the latter meaning will be used.

The designs of modern engine frames differ somewhat from earlier designs. Some of the earlier frames were referred to as the A-frame type, the crankcase type, the trestle type, and the staybolt or tie-rod type. These early frames were named according to their shape or the manner in which the parts were fastened together. Many of the features common to early engine frames have been incorporated in frames of more recent design.

As the load-carrying part of the engine, the frame of the modern engine may include such parts as the cylinder block, crankcase, bedplate or base, sump or oil pan, and end plates.

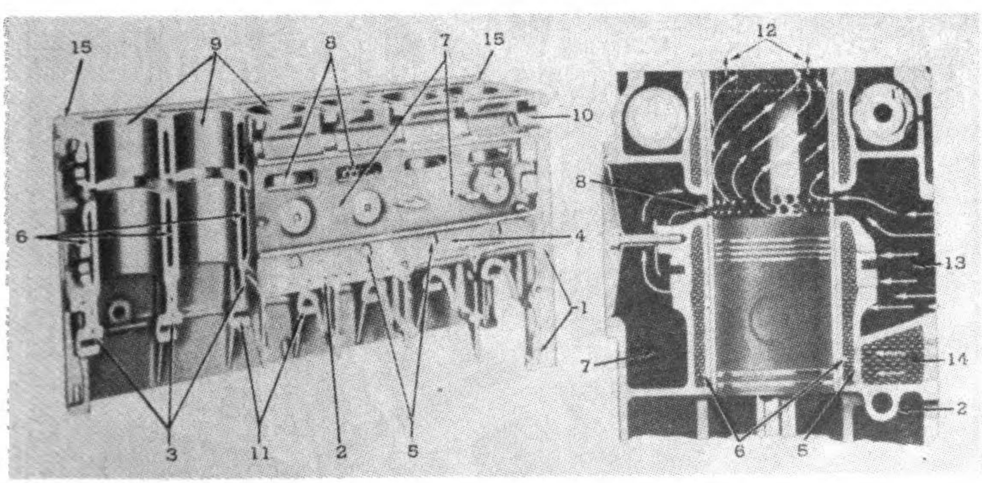
Cylinder Blocks

The part of the engine frame which supports the engine's cylinder liners and head or heads is generally referred to as the cylinder block. The blocks for most large engines are of the welded steel type construction. In this type construction, the block is welded of steel with plates located at places where loads occur. Deck plates are generally fashioned to house and hold the cylinder liners, and the uprights and other members are welded,

with the deckplates, into one rigid unit. Blocks of small high-speed engines may be of the en bloc construction. In this type construction, the block is one piece of cast iron.

A cylinder block may contain passages to allow circulation of cooling water around the liners. However, some liners are constructed with integral cooling passages. When this is the case, the cylinder block generally does not have cooling passages. Many blocks have drilled lube oil passages. Most 2-stroke cycle engines have air passages in the block.

In other words, a passage which is an integral part of an engine block may serve as a part of the engine's cooling system, lubricating system, or air system. One cylinder block is generally thought of in connection with all cylinders of an engine; however, some engines have one cylinder block for each cylinder or for each pair of cylinders. Engines having V-type or X-type cylinder arrange-



1. **Vertical Oil Passage**
2. **Oil Gallery**
3. **Oil Passage to Crankshaft**
4. **Cooling Liquid Manifold**
5. **Cooling Liquid Inlet Opening to Liner Jacket**
6. **Liner Cooling Jacket**
7. **Air Box**
8. **Air Passages to Cylinder**
9. **Bore for Cylinder Liner**
10. **Bore for Cam or Balance Shaft**
11. **Upper Half of Main Bearing**
12. **Water to Cylinder Head**
13. **Air From Blower**
14. **Water From Pump**
15. **Plugged Holes Each Corner**

Figure 3–1.—Cylinder block and crankcase (GM6-71).

ment may have a separate block for each bank of cylinders. Examples of cylinder blocks common to Navy service are shown in figures 3–1, 3–2, and 3–3.

The block shown in figure 3–1 has the crankcase as an integral part, and the entire unit is a one-piece casting of alloy cast iron. Transverse members provide rigidity and strength, ensuring alignment of the bores and bearings under all loads. The block is bored (9) to receive the cylinder liners. Note the air inlet ports (8) in the cylinder bores and the water jackets (6) which extend the full length of the bores. Air space surrounds the water jackets. Through this space, commonly called the air box (7), air is conducted from the blower to the inlet ports. Other parts which are cast integral with this type block are the upper halves of the main bearing seats (11), hand holes

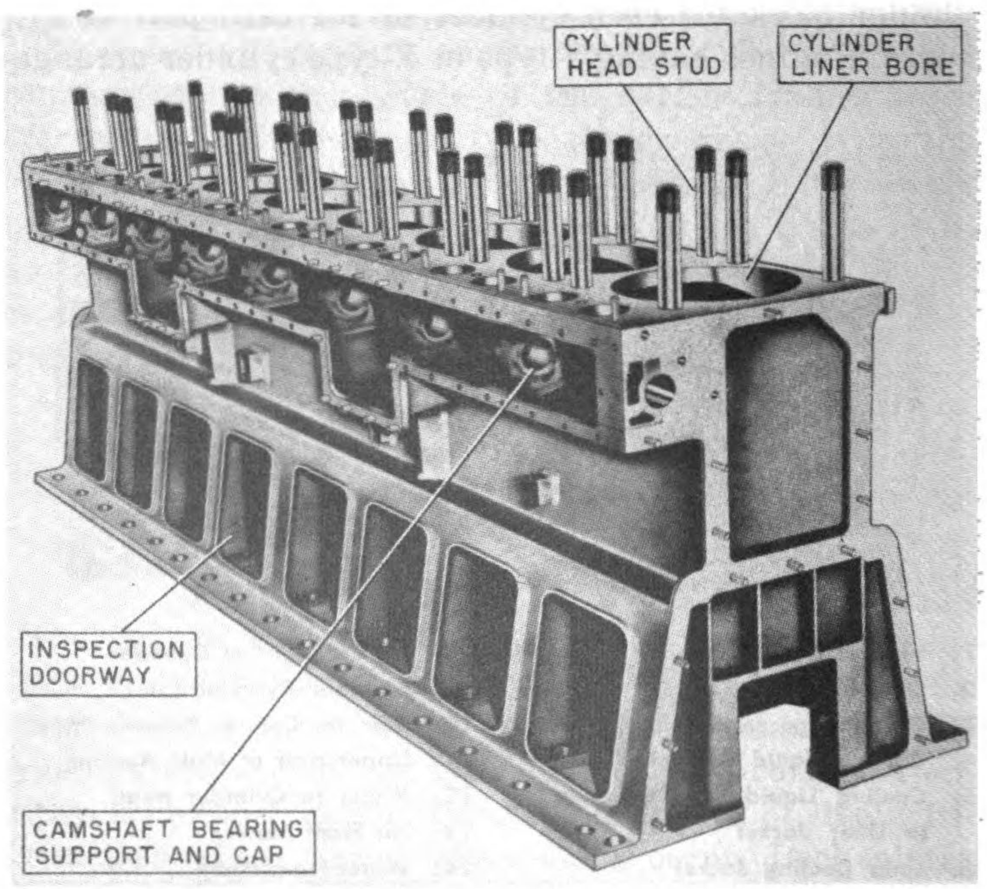


Figure 3–2.—Cylinder block (Cooper–Bessemer, GSB-8).

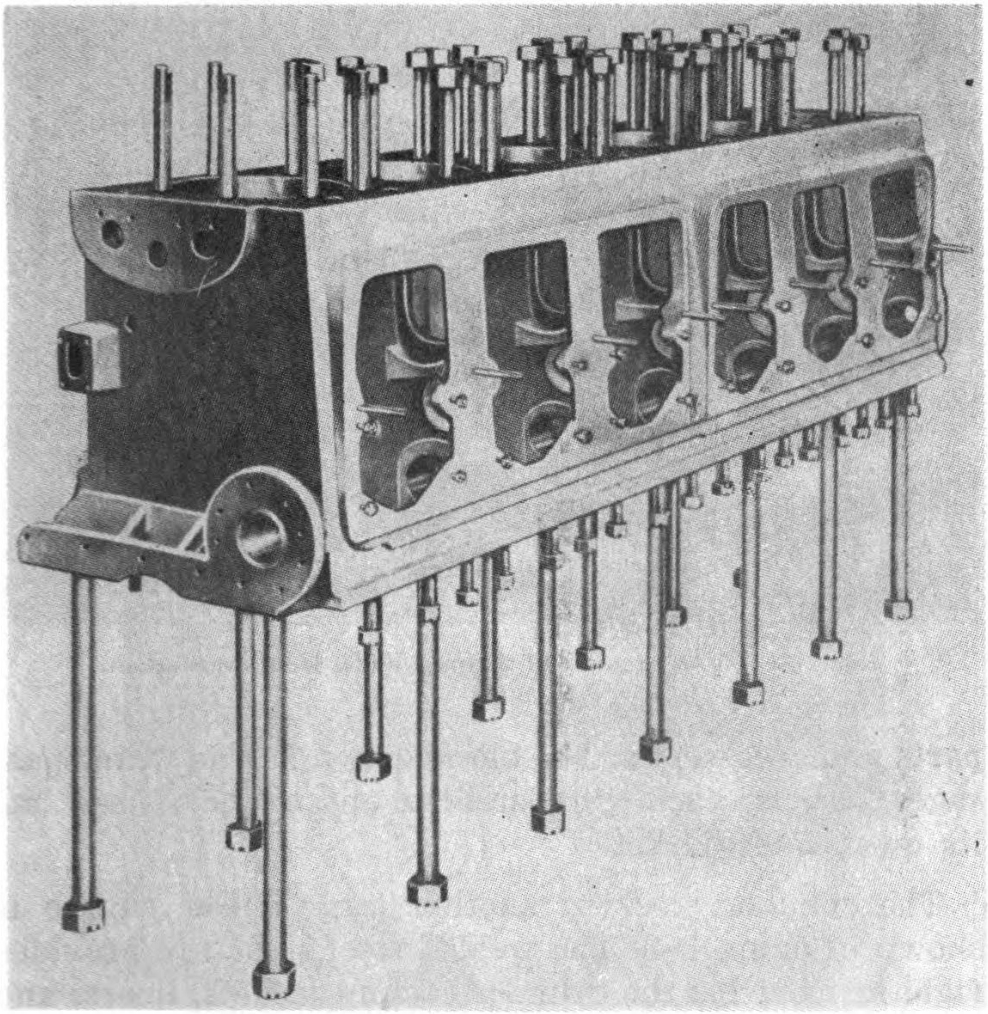


Figure 3–3.—Cylinder block (ALCO engine).

(unnumbered), bore for the cam or balance shaft (10), lubricating oil passages (1), (2), and (3), and coolant passages (4) and (5).

The cylinder block shown in figure 3–2 is somewhat larger than the one just described. It is constructed of welded steel forgings and steel plate. This type block is secured to a separate engine base, and when the two parts are bolted together, they form the frame for the main bearings which carry the crankshaft. Note that the camshaft bearing supports, consisting of forged transverse members, are an integral part of the block. Pads are welded to the block, and are machined to carry engine

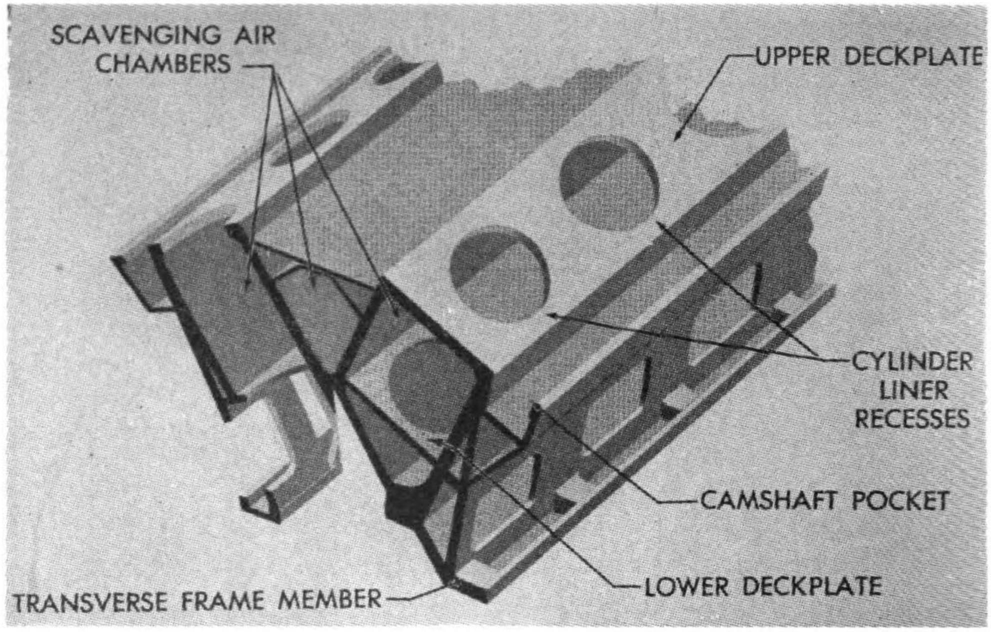


Figure 3–4.—An example of V-type cylinder block construction.

parts and accessories. The block shown has no water passages, because each cylinder liner and cylinder head has its own water jacket.

The cylinder block of another large Diesel engine is shown in figure 3–3. The welded steel structure provides rigid support for the cylinder cooling jackets, liners, and cylinder heads. The long bolts on the bottom of the block secure the unit to a separate engine part (in this case, the crankcase). (See fig. 3–6.)

The three blocks discussed so far are all from the engines with in-line cylinder arrangement. The block illustrated in figure 3–4 is representative of blocks constructed for some engines with V-type cylinder arrangement. Blocks of this type are usually constructed of forgings and steel plates welded together. The blocks of some modern engines are constructed of nonferrous metals.

In this type construction, the upper and lower deckplates of each side of the V are bored to receive the cylinder liners. The space between the decks and the space

between the two banks form the scavenging air chamber or air box. In some blocks of this type, the liner bore in the lower deckplate is made with a groove that serves as a cooling water inlet for the liner. Some V-type blocks are constructed with the mounting pads for the main bearing seats as integral parts of the forged transverse mem-

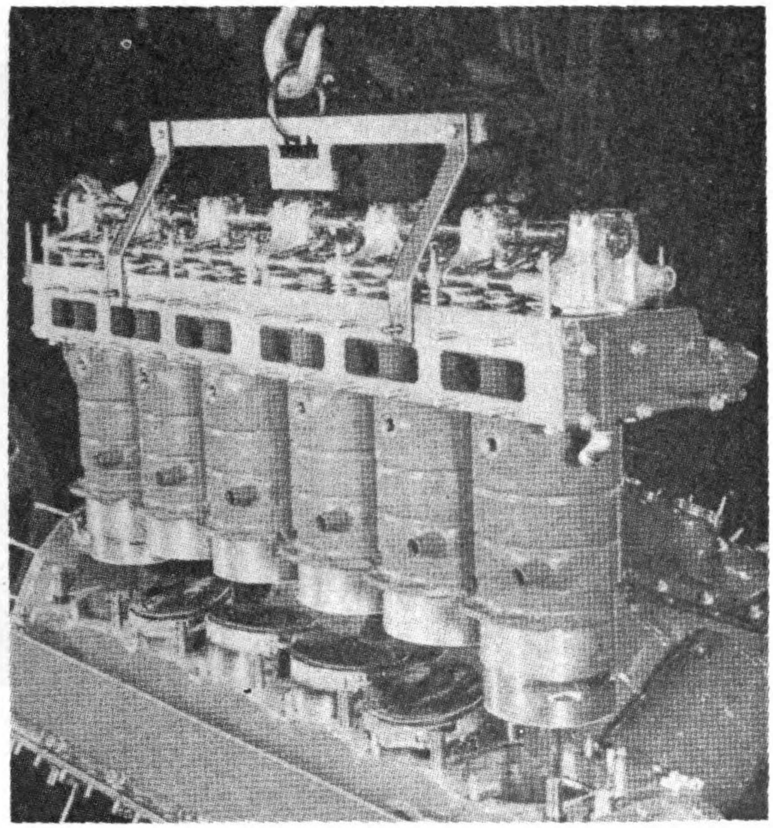


Figure 3–5.—Cylinder bank assembly (Packard).

bers at the bottom of the block. In some cases, the lower bearing seats for the camshaft are located in a pocket which is an integral part of the block. Note the camshaft pocket in figure 3–4.

Some gasoline engines of the V-type are constructed with "cylinder banks" instead of a cylinder block of the type just described. An example of a cylinder bank assembly is shown in figure 3–5.

Crankcases

The engine frame part which serves as a housing for the crankshaft is commonly called the crankcase. In some engines, the crankcase is an integral part of the cylinder block (see figs. 3–1 and 3–2), requiring an oil pan, sump, or base to complete the housing. In others, the crankcase is a separate part and is bolted to the block. Figure 3–6 illustrates a crankcase of the latter type which is used with the block shown in figure 3–3. This crankcase, an all-steel welded structure, incorporates the bolting flanges, the main bearing saddles, and an oil trough. A crankcase of this type is sometimes called the main engine base.

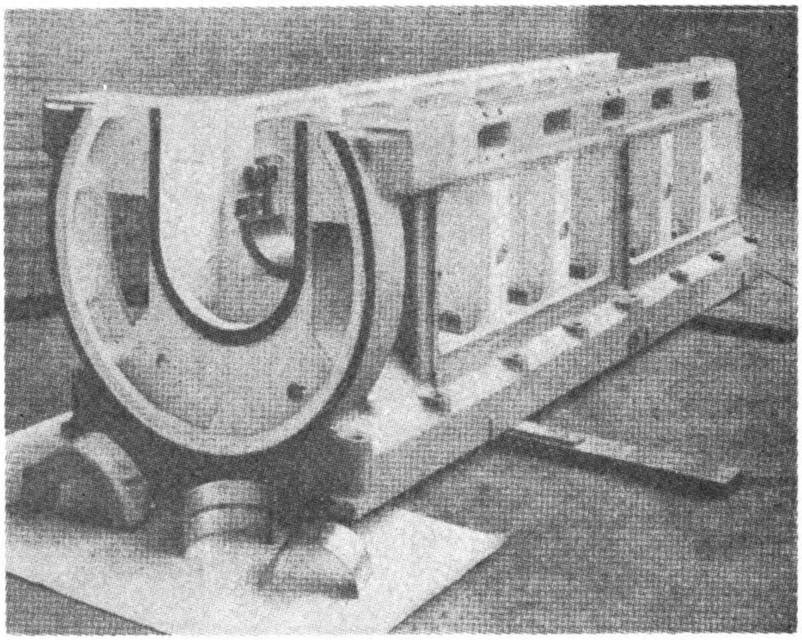


Figure 3–6.—Crankcase (ALCO).

A crankcase of a slightly different design from those just described is that used with the cylinder "bank" mentioned earlier. This crankcase consists of two aluminum castings, which are called the crankcase upper half and the crankcase lower half (fig. 3–7). The lower half of the crankcase serves as the oil pan. The upper half carries the main bearings.

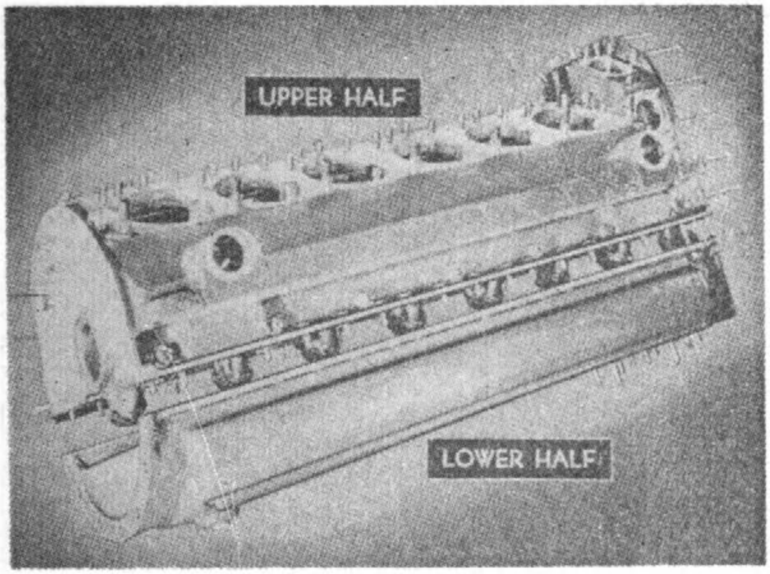


Figure 3–7.—Crankcase (Packard).

Bedplates and Bases

In large engines of early design, the support for the main bearings was provided by a bedplate. The bedplate was bolted to the crankcase and an oil pan was bolted to the bedplate when a separate oil pan was used. In some large engines of more modern design, the support for main bearings is provided by a part called the base. Figure 3–8 illustrates such a base, which is used with the block shown in figure 3–2. This type base serves as a combination bedplate and oil pan. Although similar to the crankcase shown in figure 3–6, this base requires the engine block to complete the frame for the main engine bearings. (This was not the case for the crankcase shown in figure 3–6, in which the crankshaft and the main bearings were mounted and secured completely within the crankcase.)

Sumps and Oil Pans

Since lubrication is essential for proper engine operation, a reservoir for collecting and holding the engine's lubricating oil is a necessary part of the engine structure. The reservoir may be called a sump, oil trough, or an oil pan, depending upon its design, and is usually at-

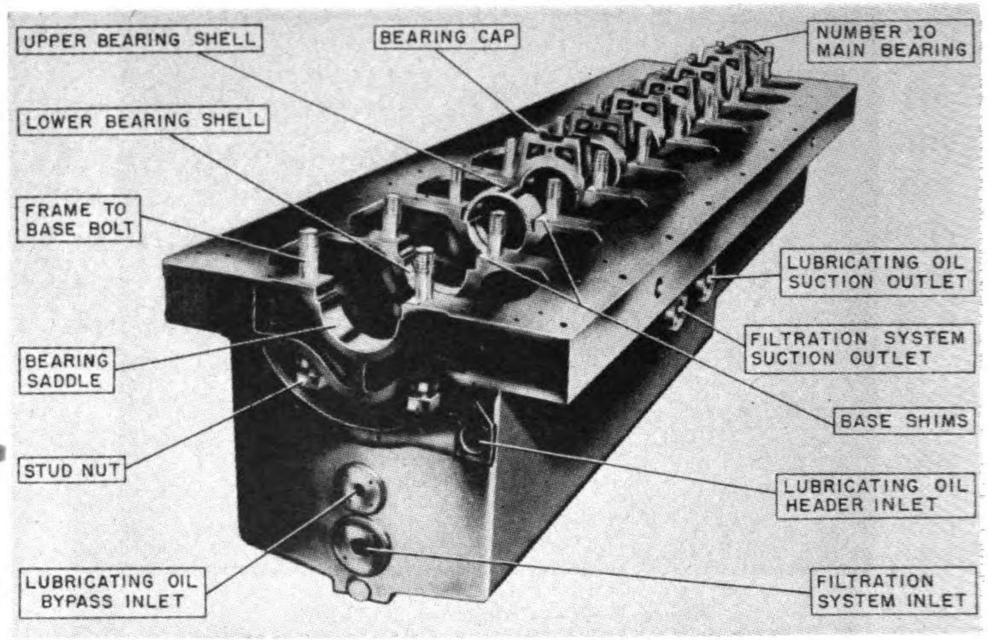


Figure 3–8.—Engine base (Cooper-Bessemer GSB-8).

tached directly to the engine. However, in dry sump engines, the sump may be located at some point relatively remote from the engine. In both cases, the reservoir serves the same purpose.

In the crankcase and the engine base shown in figures 3–6 and 3–8, the oil sump is an integral part of the base or crankcase, which has functions other than just being an oil reservoir. Many of the smaller engines do not have a separate base or crankcase; instead, they have an oil pan, which is secured directly to the bottom of the block. The block shown in figure 3–1 utilizes such a pan. In most cases, an oil pan serves only as the lower portion of the crankshaft housing and as the oil reservoir.

End Plates

Some engines have flat steel plates attached to each end of the cylinder block. End plates add rigidity to the block and provide a surface to which may be bolted housings for such parts as gears, blowers, pumps, and generators. An end plate and gasket for the block in figure 3–1 are shown in figure 3–9.

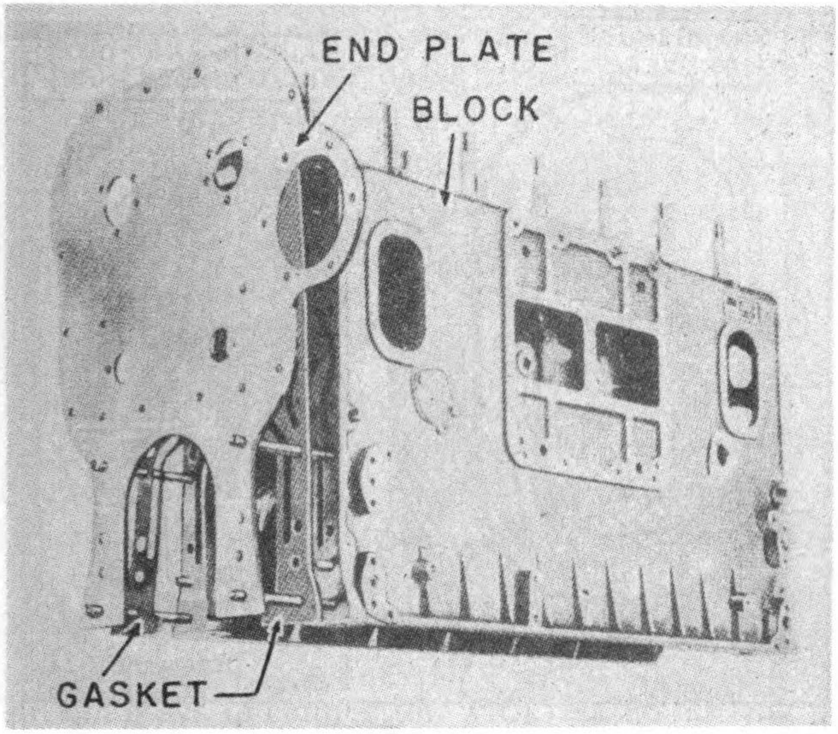


Figure 3–9.—Front end plate and attaching parts (GM 6-71).

Access Openings and Covers

Many engines, especially the larger ones, have openings in some part of the engine frame. (See figs. 3–2, 3–3, and 3–6.) These openings permit access to the cylinder liners, main and connecting rod bearings, injector control shafts, and various other internal engine parts. Access doors are usually secured with handwheel or nut-operated clamps and are fitted with gaskets to keep dirt and foreign material out of the engine's interior. On some engines, the covers (sometimes called doors or plates) to access openings are constructed to serve as safety devices. A safety cover is equipped with a spring-loaded pressure plate. The spring maintains a pressure which keeps the cover sealed under normal operating conditions. In the event of a crankcase explosion or extreme pressure within the crankcase, the excess pressure overcomes the spring tension and the safety cover permits the ac-

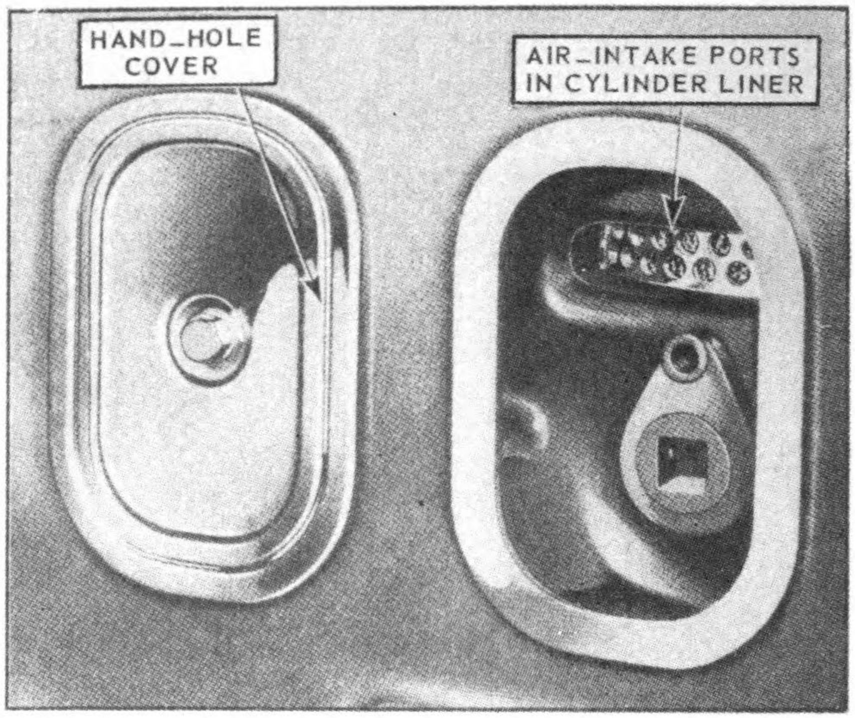


Figure 3—10.—Cylinder block hand-hole cover (GM 6-71).

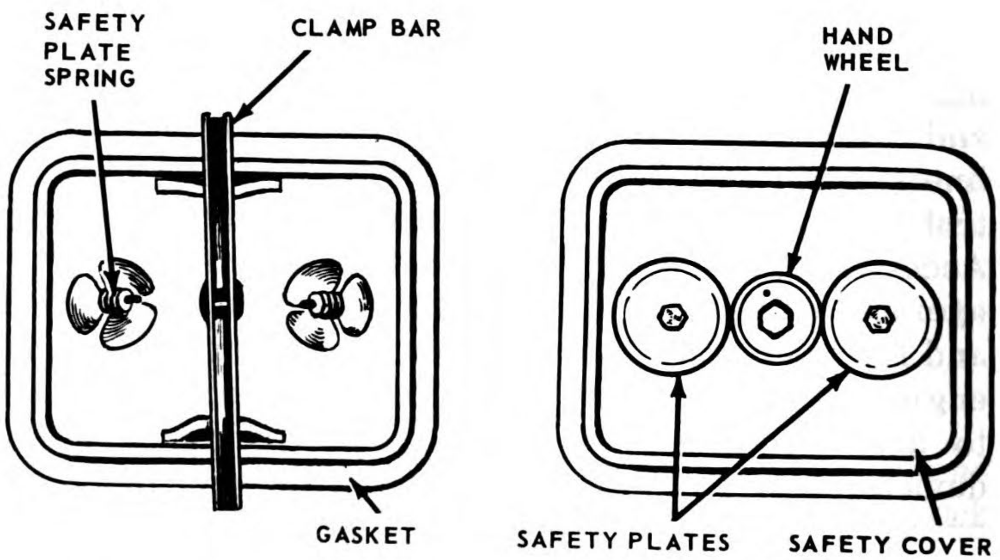


Figure 3—11.—Safety type crankcase handhole cover (GM 278A models). Left view, inside of cover. Right view, outside of cover.

cess opening to act as an escape vent. The release of excess pressure prevents damage to the engine.

The access opening and cover for one of the blocks discussed earlier is shown in figure 3–10. The cross-section of this cover and its position on the block can be seen in the right-hand view of figure 3–1. A safety cover and its parts are shown in figure 3–11.

Bearings

The bearings of an engine make up an important group of parts. Some bearings remain stationary in performing their function while others move. One principal group of stationary bearings in an engine are those which support the crankshaft. These bearings are generally called main engine bearings. (See figs. 3–1, 3–6, and 3–8.) Additional information on these and other bearings is given in subsequent chapters in connection with related moving parts.

CYLINDER ASSEMBLIES

The cylinder assembly completes the structural framework of an engine. As one of the main stationary parts of an engine, the cylinder assembly, along with various related working parts, serves to confine and release the gases. For the purpose of this discussion, the cylinder assembly will be considered as consisting of the head, the liner, the studs, and the gasket (see fig. 3–12). The other engine parts shown in figure 3–12, many of which involve motion, are discussed later in this course.

The design of the parts of the cylinder assembly varies considerably from one type of engine to another. Regardless of differences in design, however, the basic components of all cylinder assemblies function, along with related moving parts, to provide a gas- and liquid-tight space. Differences other than in design will be found in cylinder assemblies. For example, a gasket is necessary between the head and block of most cylinder assemblies. However, such gaskets are not used on all engines. When a gasket is not a part of the assembly, the mating surfaces of the head and block are accurately machined to form a

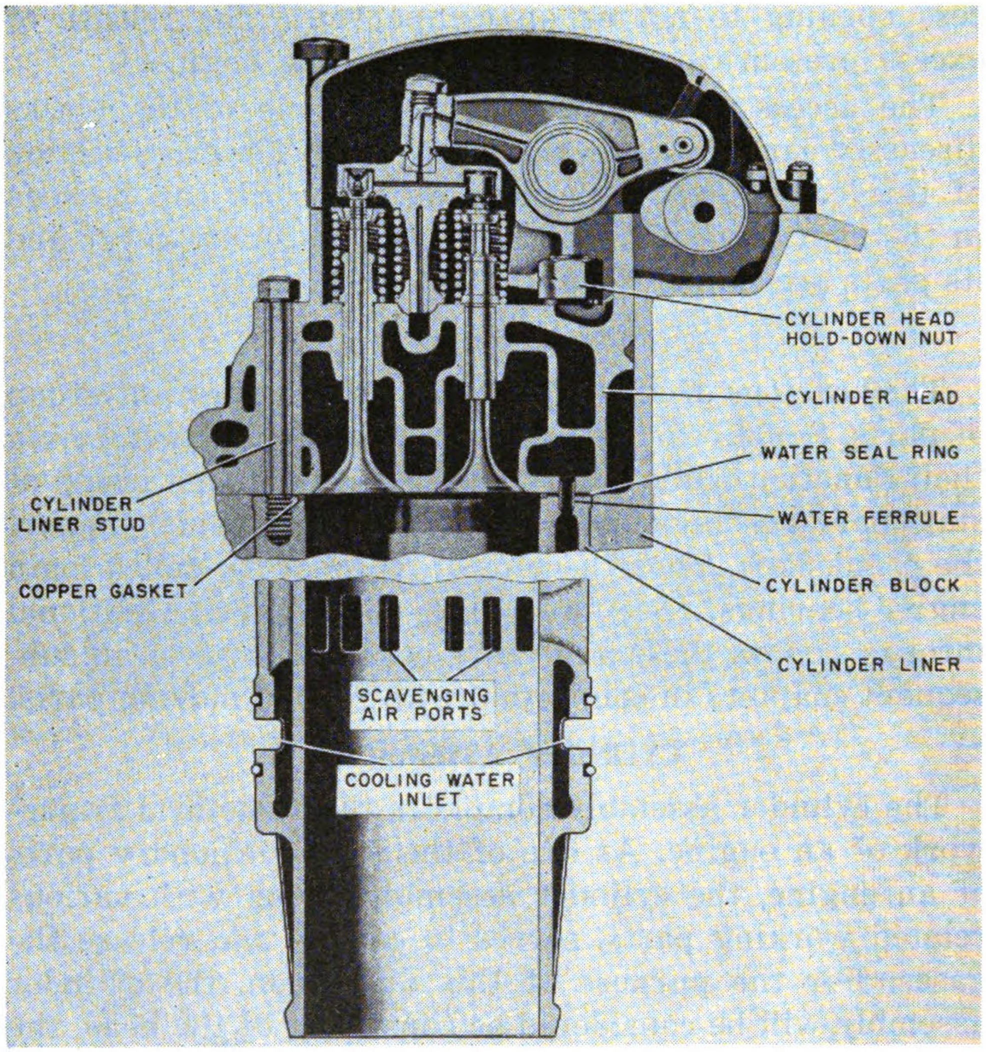


Figure 3–12.—Principal stationary parts of a cylinder assembly (GM 278A models).

seal between the two parts. Other differences in cylinder assemblies exist, some of which are pointed out in the discussion that follows.

Cylinder Liners

The barrel or bore in which an engine piston moves back and forth may be an integral part of the cylinder block or it may be a separate sleeve or liner. The first type, common in gasoline engines, has the disadvantage of not being replaceable. When excessive wear occurs in a barrel of this type, the barrel must be rebored and

honed. Reconditioning of this nature cannot be repeated indefinitely and, in time, the entire block must be replaced. Another disadvantage is the inconvenience, especially in the case of large engines, of removing the entire cylinder block from a vessel in order to recondition the cylinders. For these reasons, practically all Diesel engines are constructed with replaceable cylinder liners.

The material of a liner must withstand the extreme heat and pressure developed within the cylinder and, at the same time, permit the piston and rings to move with a minimum of friction. Close-grained cast iron is the material most commonly used for liner construction; however, steel is sometimes used. Some liners are plated on the wearing surface with porous chromium. The chromium has greater wear-resistant qualities than other materials used. Also, the pores in the plating tend to hold the lubricating oil and thereby aid in maintaining the lubrication film which is necessary to reduce friction and wear.

Six cylinder liners of the replaceable type are shown in figure 3–13. These liners illustrate some of the differences in the design of liners and the relative size of the engines represented.

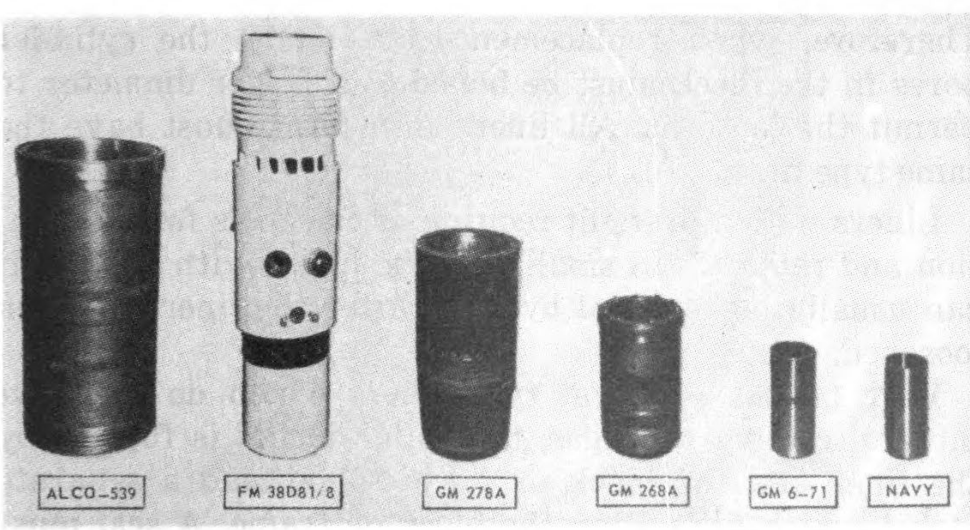


Figure 3–13.—Cylinder liners of Diesel engines.

Cylinder liners may be divided into two general classifications or types: DRY and WET. The dry type liner does not come in contact with the coolant; instead, it fits closely against the wall of the cooling jacket in the cylinder block. With the wet type liner, the coolant comes in direct contact with the liner. Wet liners may be of the type with which circumferential sealing devices are necessary, or they may be of the type which contains integral cooling passages. Liners with integral cooling passages are sometimes referred to as water-jacketed liners.

DRY LINERS.—Liners of this type have relatively thin walls compared with liners of the wet type. The two smaller liners in figure 3–13 are of the dry type. The cross section of the liner second from the right in figure 3–13 can be seen in the right-hand view of figure 3–1. Note that the coolant circulates in passages in the block and does not come in contact with the liner.

Liners of the dry type are installed in some engines with a press fit and in others with a loose fit. In the case of engines using the type of block shown in figure 3–1, some engines were fitted with press fit liners and others had liners with a loose fit. Manufacturers recommend that, when replacements are necessary, liners with a press fit be replaced with those having a loose fit. In such cases, the liners for both press and loose fits are identical. Therefore, when replacements are made, the cylinder bores in the block must be honed to a larger diameter to permit the loose fit. All liners in a block must have the same type fit.

Liners with a press fit require special tools for installation and removal. In small engines, liners with a loose fit can usually be removed by hand after the liner has been loosened.

WET LINERS.—In wet type liners which do not have integral cooling passages, the water jacket is formed by the liner and the block or by the liner and a separate jacket which fits within the block or frame. A seal must be provided at both the combustion and crankshaft ends

of the cylinders to prevent leakage. Generally, the seal at the combustion end of a liner consists of either a gasket under a flange or a machined fit. Rubber or neoprene rings generally form the seal at the crankshaft end of the liner. Liners of this type are so constructed as to permit lengthwise expansion and contraction, and the walls are strong enough to withstand the full working pressure of the combustion gases. In figure 3–13, the liner with the largest diameter is an example of this type of wet liner. Note the grooved flange at the top and the seal ring grooves at the lower end. The groove in the flange and the tongue of the cylinder head make a metal-to-metal joint and seal. The joint between the flange and the cooling jacket is sealed with a non-hardening sealing compound. A cross section of a wet type liner is shown in figure 3–14.

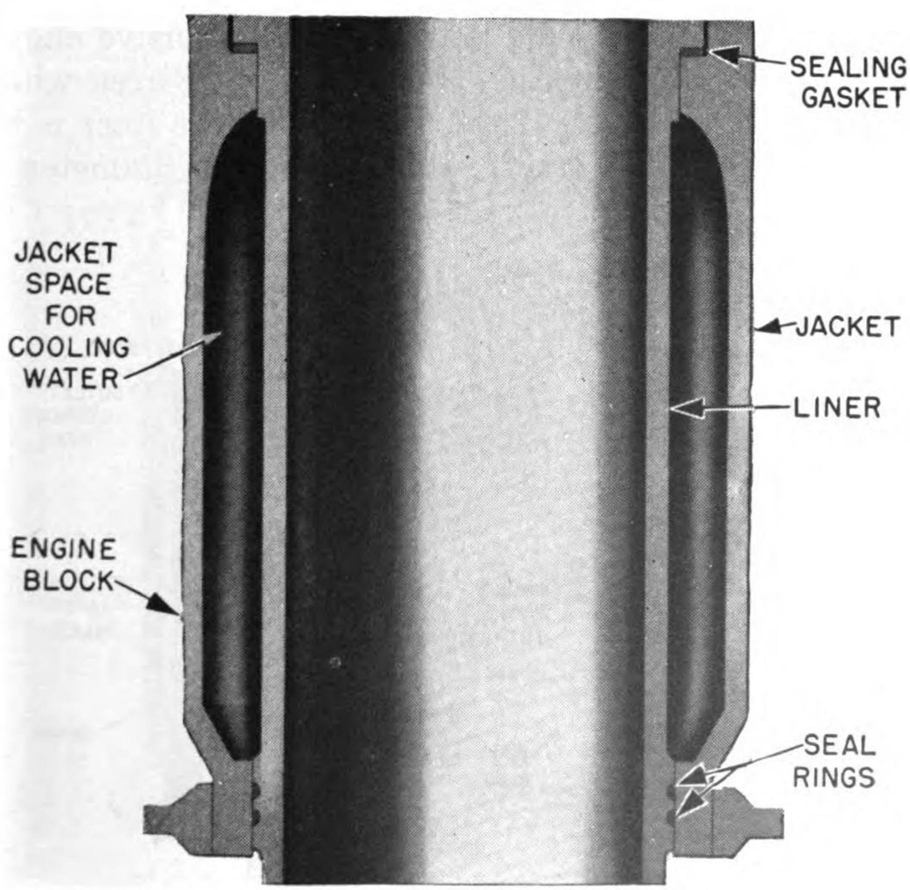


Figure 3–14.—Cross section of a wet type cylinder liner.

WATER-JACKETED LINERS.—A cylinder sleeve of this type has its own coolant jacket as an integral part of the liner assembly. The jacket may be cast on, shrunk on, or sealed on the liner. The water is admitted into the lower section of the jacket and leaves through the top, as illustrated in figure 3–15. The liner shown is that of a 4-stroke cycle engine. Most 2-stroke cycle engines are equipped with jacket-type liners, since such liners provide the most effective means of establishing a watertight seal around the ports.

Another feature of some liners is the counterbored area. Such an area is identified in B of figure 3–15. The counterbore extends down to the top point of travel of the firing ring. The diameter of the liner in the counterbored area is slightly larger than the diameter in the area of piston ring travel. The counterbore is provided to prevent the formation of a ridge or lip on the liner surface at the upper point of ring travel. After extensive engine operation, the liner surface may wear in the area where the rings make contact. If the diameter of the liner is the same throughout its length, the increase in diameter in

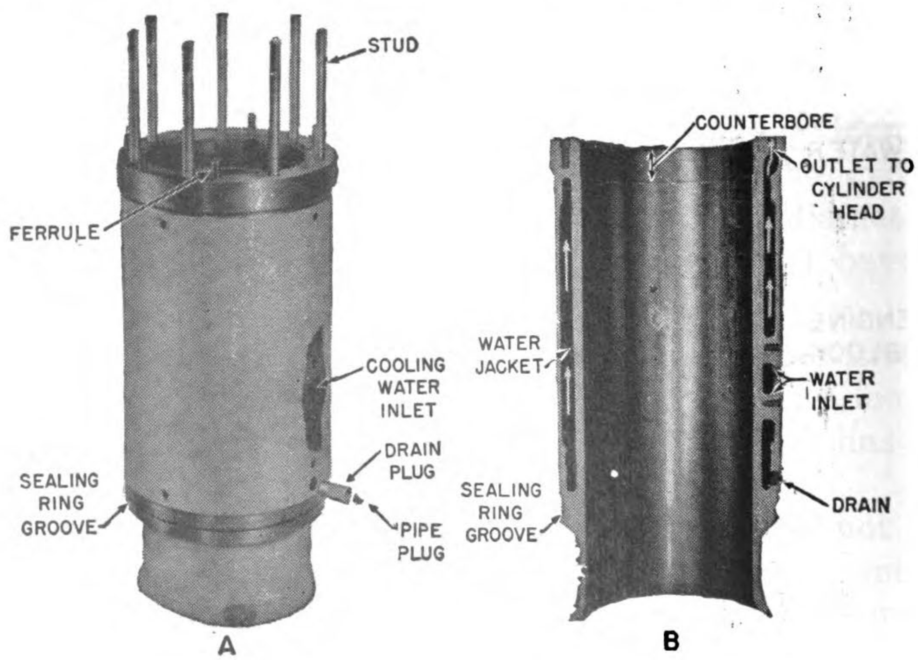


Figure 3–15.—Jacket-type liner (Cooper-Bessemer, GSB-8).

the ring contact area results in the formation of a ridge at the upper limit of firing ring travel. A counterbore or larger diameter above this point prevents the wear of the liner from forming such a ridge or lip. A lip on the surface of a liner may cause broken piston rings and possibly extensive damage to an engine.

The liner in figure 3–15 and the two center liners in figure 3–13 have cast-on jackets; that is, the jacket is cast as an integral part of the liner, in these cases. This is not true of the longest liner shown in figure 3–13. Instead of being cast as an integral part of the liner, the water jacket here is sealed on the liner with rubber seal rings. Details of a liner assembly with a sealed-on jacket are shown in figure 3–16.

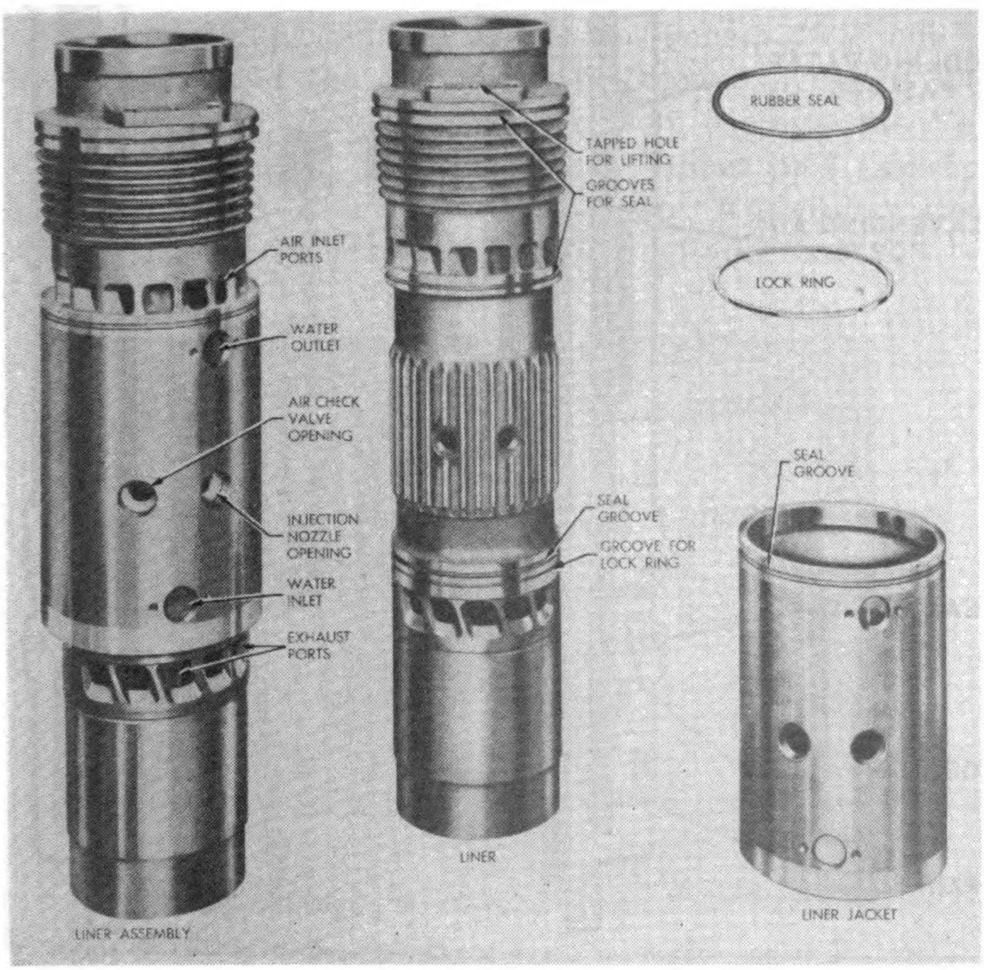


Figure 3–16.—Cylinder liner assembly with sealed-on jacket (FM 38 D 8 1/8).

Of the four jacket-type liners shown (figs. 3–13, 3–15, and 3–16) and discussed, note that three have ports. In the largest of these three, the location of the ports (see fig. 3–16) eliminates the seal of the water jacket as a problem with respect to the air ports. In the case of the other two liners (two center liners in fig. 3–13), there

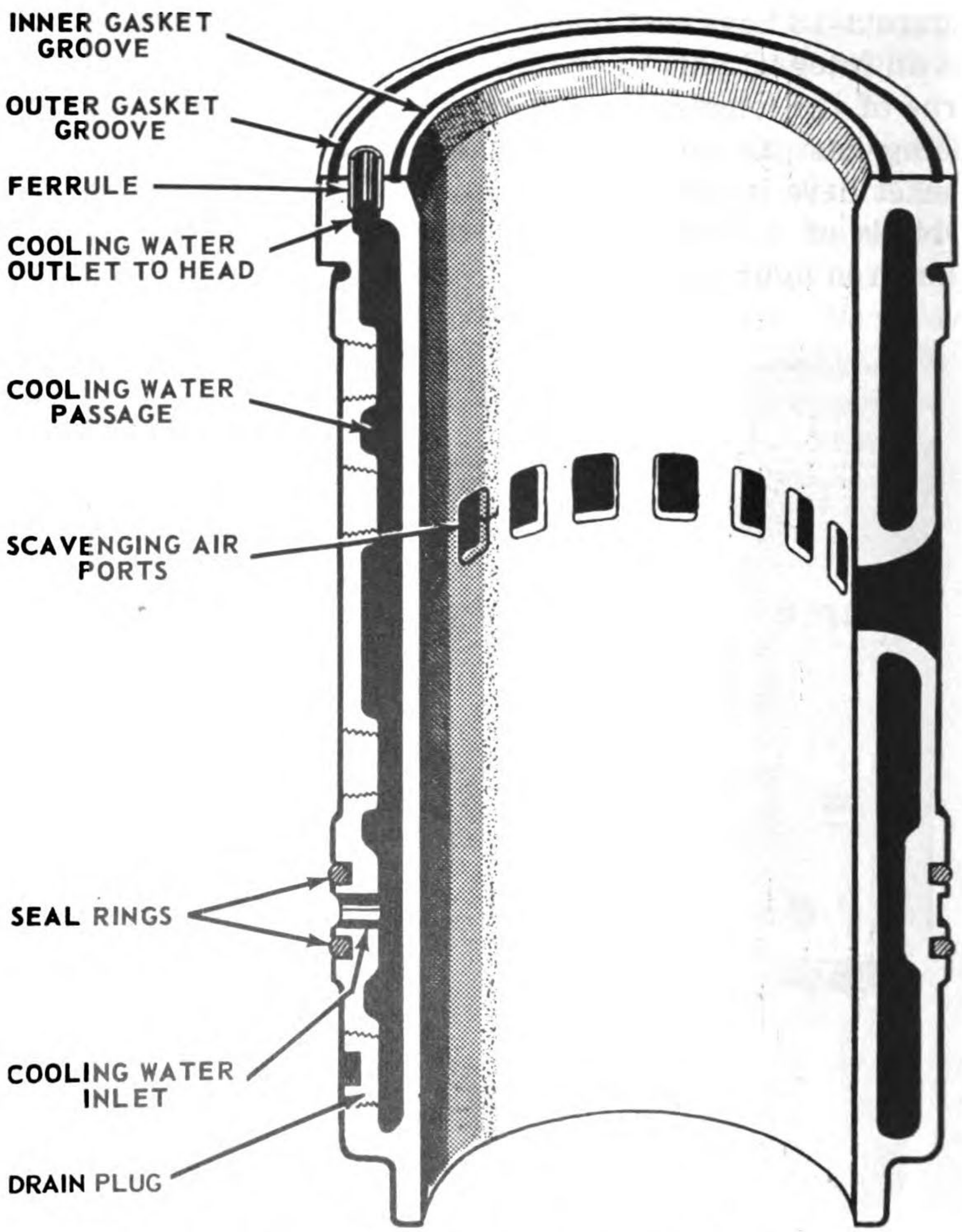


Figure 3–17.—Cast jacket-type liner with air ports (GM 268A models).

is no problem of leakage, since the ports are cast as a part of the assembly. In the cast jacket-type liner, the water jacket is formed by the inner and outer walls of the liner. The ports divide the water space into lower and upper spaces, which are connected by vertical passages between the ports. This type of construction is illustrated in figure 3–17. The cross section shown is that of the smaller of the two center liners in figure 3–13.

The cylinder liners discussed to this point are representative of those used in Diesel engines. In gasoline engines, the bore of a cylinder is generally an integral part of the cylinder block or of the individual cylinder assembly. The construction of the latter is shown in figure 3–18. Note the similarity of this cylinder assembly to the liners just discussed.

The individual cylinder shown in figure 3–18 is one of the cylinders of the cylinder bank shown in figure 3–5. The cylinder is forged as a unit from a single piece of steel, and is bolted to the crankcase upper half (see fig. 3–7) by means of the mounting flange. A stainless steel water jacket is welded around each cylinder barrel.

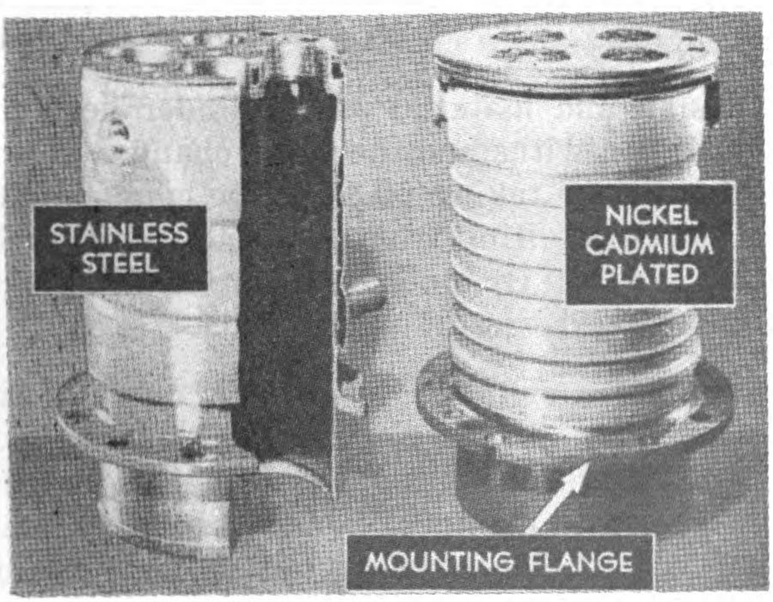


Figure 3–18.—Individual cylinder of a gasoline marine engine (Packard).

Cylinder Heads

The liners or bores of an internal combustion engine must be sealed tightly to form the combustion chambers. In most Navy engines, except for engines of the opposed-piston type, the space at the combustion end of a cylinder is formed and sealed by a cylinder head which is a separate unit from the block. An exception to this is the cylinder shown in figure 3–18. In this cylinder, the head is a part of the cylinder assembly.

A number of engine parts which are essential to engine operation may be found in or attached to the cylinder head. The cylinder head may house intake and exhaust valves, valve guides and valve seats, or only exhaust valves and related parts. Rocker arm assemblies are frequently attached to the cylinder head. The fuel injection valve is almost universally in the cylinder head or heads of a Diesel engine, while the spark plugs are always in the cylinder head of gasoline engines. Cylinder heads of a Diesel engine may also be fitted with air starting valves, indicator cocks, and safety valves. The parts which may be attached to or housed in the cylinder head are covered in more detail in subsequent chapters of this training course.

The design and material of a cylinder head must be such that it can withstand the rapid changes of temperature and pressure taking place in the combustion space, and the stress resulting from the head's being bolted securely to the block. Cylinder heads are almost universally made of heat-resisting alloy cast iron.

The number of cylinder heads found on engines varies considerably. Small engines of the in-line cylinder arrangement utilize one head for all cylinders. A single head serves for all cylinders in each bank of some V-type engines. Large Diesel engines generally have one cylinder head for each cylinder. Some engines use one head for each pair of cylinders.

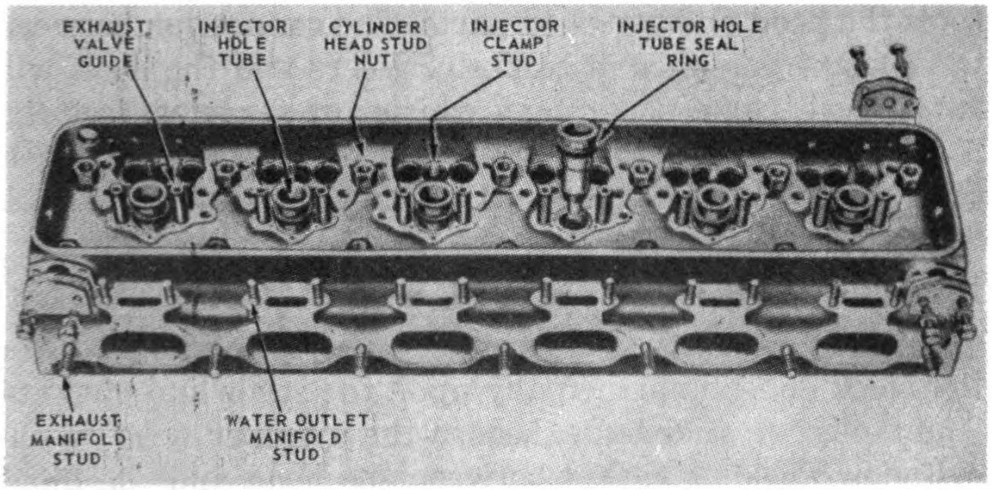


Figure 3–19.—Cylinder head (GM 6-71).

A cylinder head of the type used to seal all cylinders of a block is shown in figure 3–19. This head is used with the block illustrated in figure 3–1. Three heads of the individual-cylinder type are shown in figure 3–20. The head on the right is the type used for each of the cylinders of the block shown in figure 3–2. The two heads on the left are used on V-type Diesel engines. A cross section of the head on the extreme left is shown in figure 3–12.

Coolant passages, common to most cylinder heads, are provided in each of the heads shown in 3–20. The coolant enters the head from the cylinder block or liner and

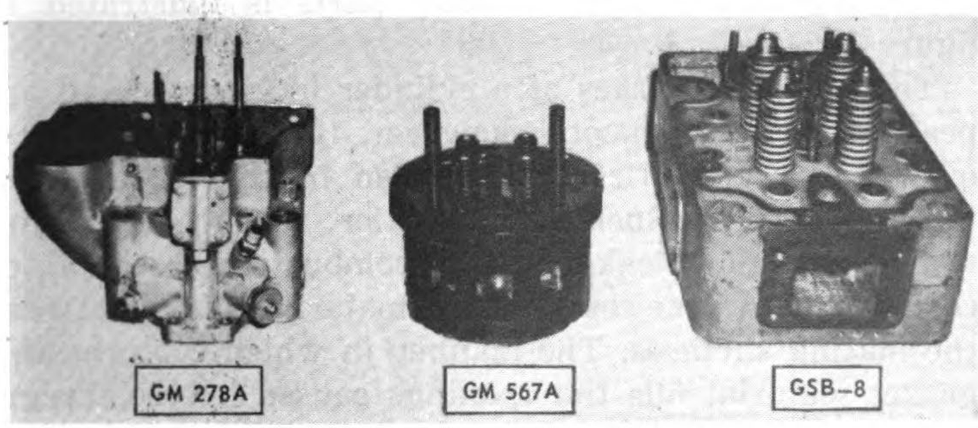


Figure 3–20.—Cylinder heads for individual cylinders.

cools the head and attached parts. The connection between the coolant passages in blocks or liners and the head will vary. Such connections may consist of ferrules (see fig. 3–12) or similar connections, or of outside jumper lines. (See chapter 8 for additional information on engine cooling systems.)

Cylinder Head Studs and Gaskets

In most cases, the seal between the cylinder head and the block depends principally upon the studs and gaskets. The studs, or stud bolts, secure the cylinder head to the cylinder block. A gasket between the head and the block is compressed to form a seal when the head is properly tightened down.

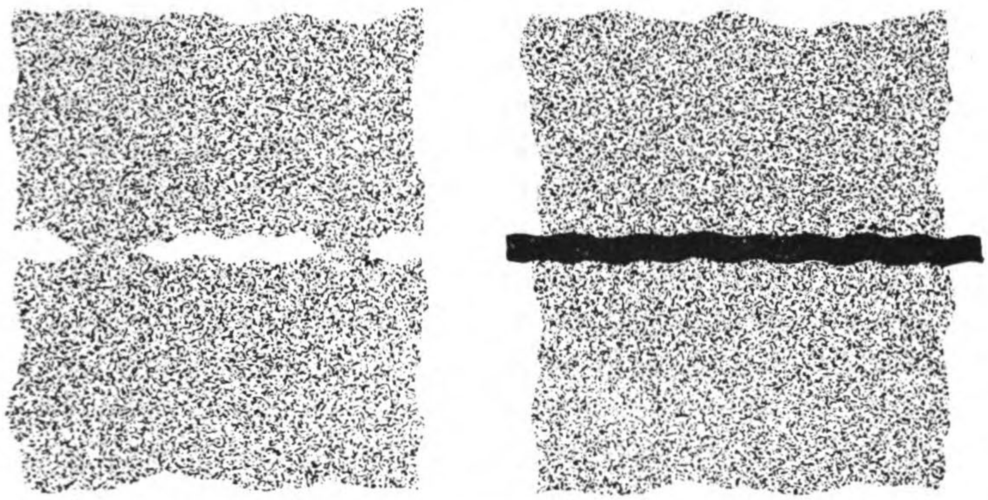
STUDS.—Round rod, generally of alloy steel, is used for cylinder head studs. Threads are cut on both ends, and those which screw into the block are generally of a much tighter fit than those on the nut end. A tighter fit in the block aids in preventing the stud from unscrewing when the stud nuts are removed. In most cases, studs which are in good condition should not be removed from a cylinder block.

Sets of cylinder head studs in position in cylinder blocks can be seen in figures 3–2 and 3–3.

GASKETS.—Even though gasket design is quite varied, all gaskets have "compressibility" as a common property. The principle by which this property is put to use in forming a seal between mating parts is illustrated in figure 3–21.

The mating surfaces of a cylinder block and head appear to be quite smooth; however, if highly magnified, existing irregularities can be seen in the surfaces, as illustrated in A. Such irregularities, though slight, are sufficient to allow leakage of the combustion gases, oil, or coolant unless some compressible material is used between the mating surfaces. The manner in which compressible gasket material fills the openings caused by the irregularities of the two mating surfaces is illustrated in B.

Material used in the manufacture of gaskets varies as



A – SURFACE WITHOUT GASKET

B – GASKET IN PLACE

Figure 3–21.—The principle of a gasket.

widely as does gasket design. Gaskets are made from copper and other relatively soft metals, laminated steel sheets, fiber, cork, rubber, synthetic rubber, and a combination of materials such as copper and asbestos. Combinations of gaskets, seal rings, and grommets or similar devices may be used to prevent leakage of oil, water, and gas between a cylinder block and head.

Three types of gaskets are shown in figure 3–22. The

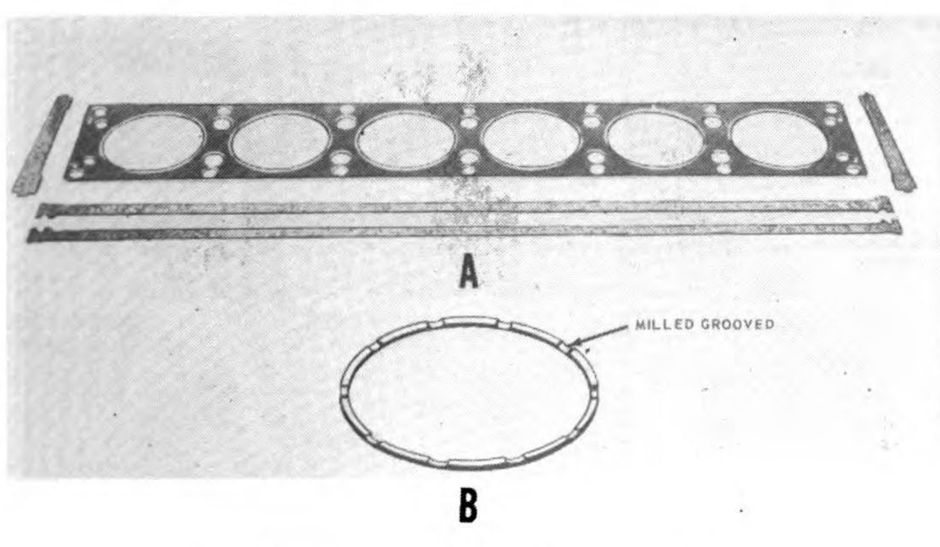


Figure 3–22.—Types of cylinder head gaskets.

cylinder block shown in figure 3–1 uses the gaskets illustrated in A. The larger unit is a five-sheet, laminated steel gasket. Copper grommets are used around the oil and water openings of the block and head. The four smaller gaskets are made of cork and fit around the outside edge of the mating surfaces of the block and head. The gasket shown in B is of the type used in combination with other gaskets to seal a single cylinder. This is the outer gasket of the combination seal and is made of copper. An inner seal ring of bronze is also used in this installation. See figure 3–23 for the details of this type cylinder head seal. Note the water seal and water ferrule.

ENGINE MOUNTINGS

The devices used to secure an engine in place are not an actual part of the engine. However, a discussion of these devices is included here since they are obviously essential for installation purposes and since they serve an important part in reducing the possibility of damage to an engine and the mechanism which it drives.

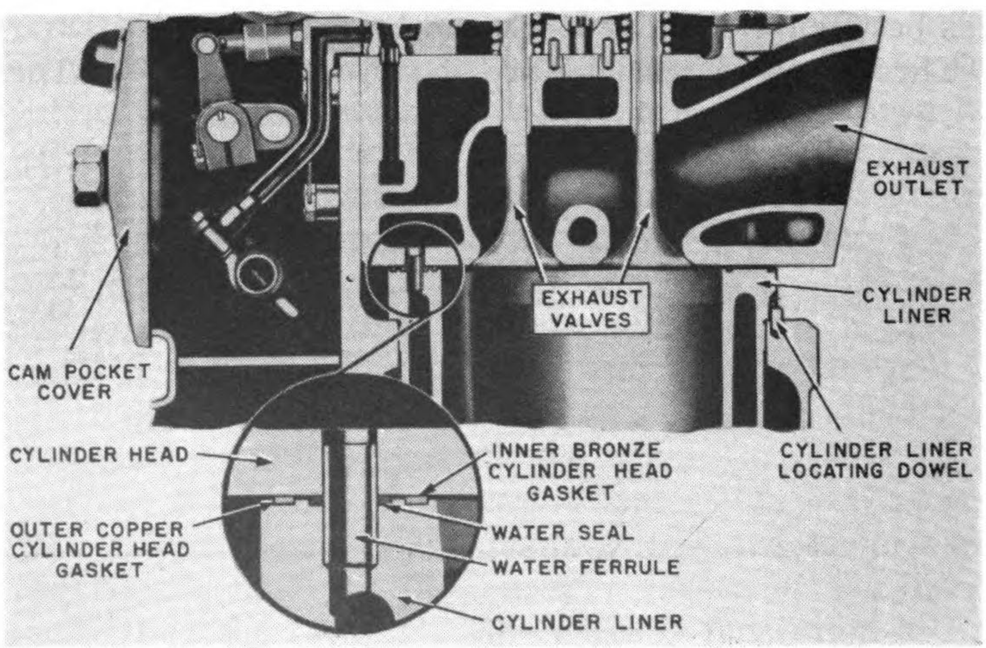


Figure 3–23.—Combination gasket seal for a cylinder head (GM 268A).

Different terms are used to identify the devices that secure an engine to a vessel. Such terms as base, subbase, bed, frame, rails, mountings, securing devices, etc., appear in various engine instruction manuals. To avoid confusion with the engine base already discussed in this chapter the supporting and connecting pedestal between an engine and the structure of a vessel will be called a subbase in the discussion which follows. The devices used to fasten the subbase to the vessel will be identified here as securing devices.

SUBBASES.—The size and design of the subbase depends upon the engine involved and its use. In many cases, the engine and the mechanism which it drives are mounted on a common subbase. One advantage of mounting both units on a common subbase is that misalignment is less likely than when the units are mounted separately. Figure 3–24 shows an engine and reduction gear mounted on a

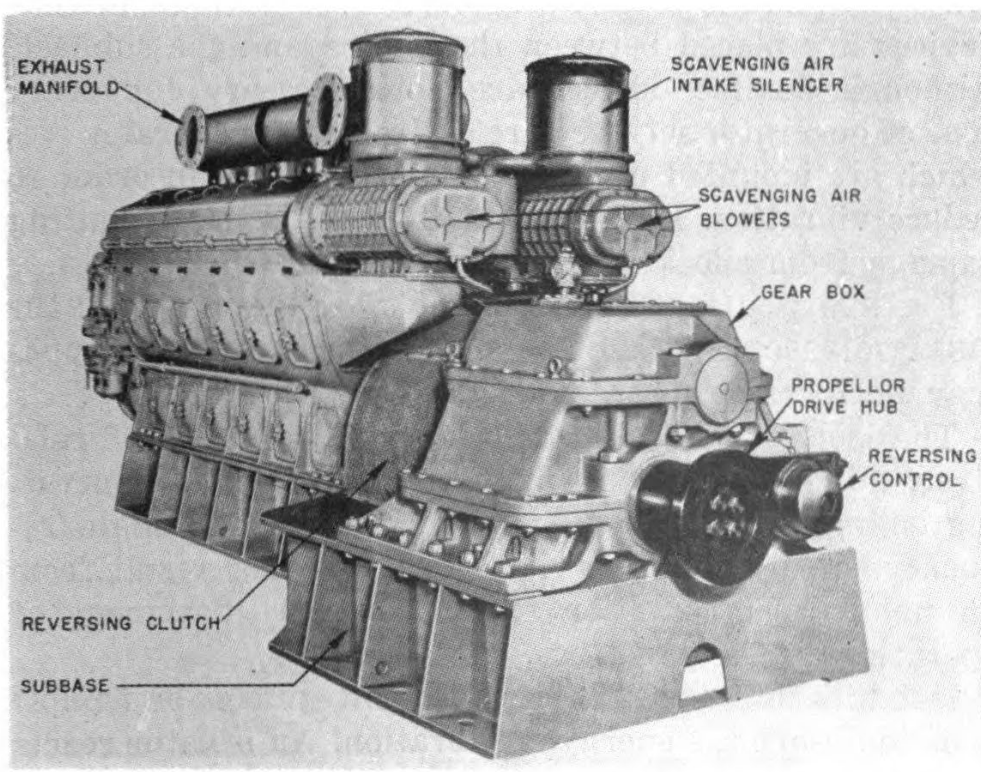


Figure 3–24.—Engine and reduction gear mounted on a common subbase (GM 12-567 ATL(P)).

common subbase. Diesel engine-generator sets are secured to a common subbase in most cases.

A different type of mounting involves the use of hand-fitted chocks, or blocks, between the engine and the structure of the vessel. Bolts are used to secure the engine rigidly in place and maintain alignment. A mounting of the block type is used with the engine base shown in figure 3–8.

SECURING DEVICES.—The devices used to fasten a subbase to the structure of a vessel may be classified, in general, as rigid or flexible. Propulsion engines are secured rigidly to avoid misalignment between the engine, reduction gear (or other driven mechanisms), and the propeller shaft. Engines which drive auxiliary equipment may be secured by either rigid or flexible devices.

In installations where rigidity is of prime importance, BOLTS are used as the securing devices. Flexible securing devices are generally used between the subbase of a generator set and the vessel's structure. In some cases, flexible devices are placed between the engine and the subbase. Although flexible devices are not necessary for every type of generator set, they are desirable for generator sets which are mounted near the side of the hull, in order to reduce vibration. Flexible devices also aid in preventing damage from shock loads imposed by external forces.

Flexible securing devices are of two general types: the VIBRATION ISOLATOR and the SHOCK ABSORBER. Both types may be incorporated in one device.

The isolator is designed to absorb the forces of relatively minor vibrations, which are common to an operating engine. Such vibrations are referred to as high-frequency, small-amplitude vibrations, and they result from an unbalanced condition created by the movement of operating engine parts.

Isolators may be equipped with coil springs or flexible pads to absorb the energy of vibration. An isolator reacts in the same manner, whether it is of the spring type or of the flexible pad type. Examples of both types of isolators

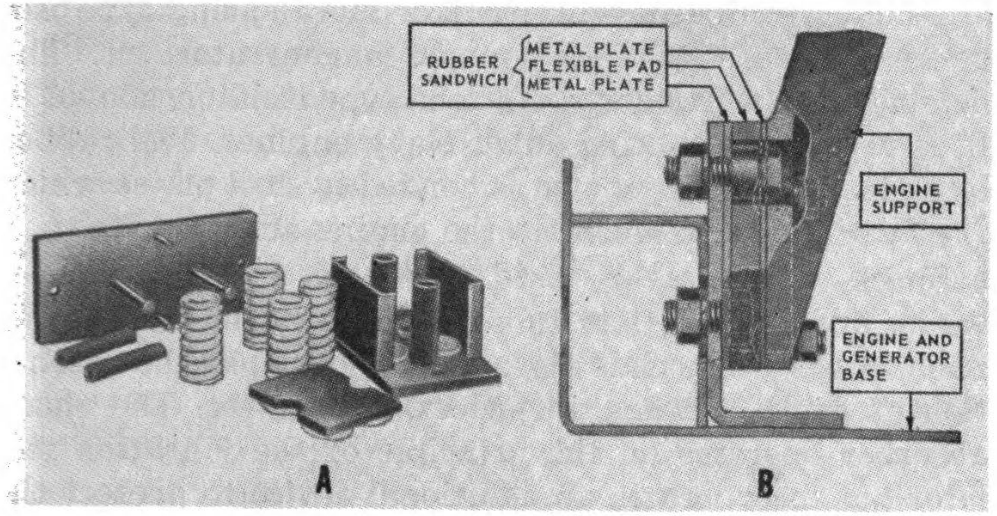


Figure 3–25.—Vibration isolators.

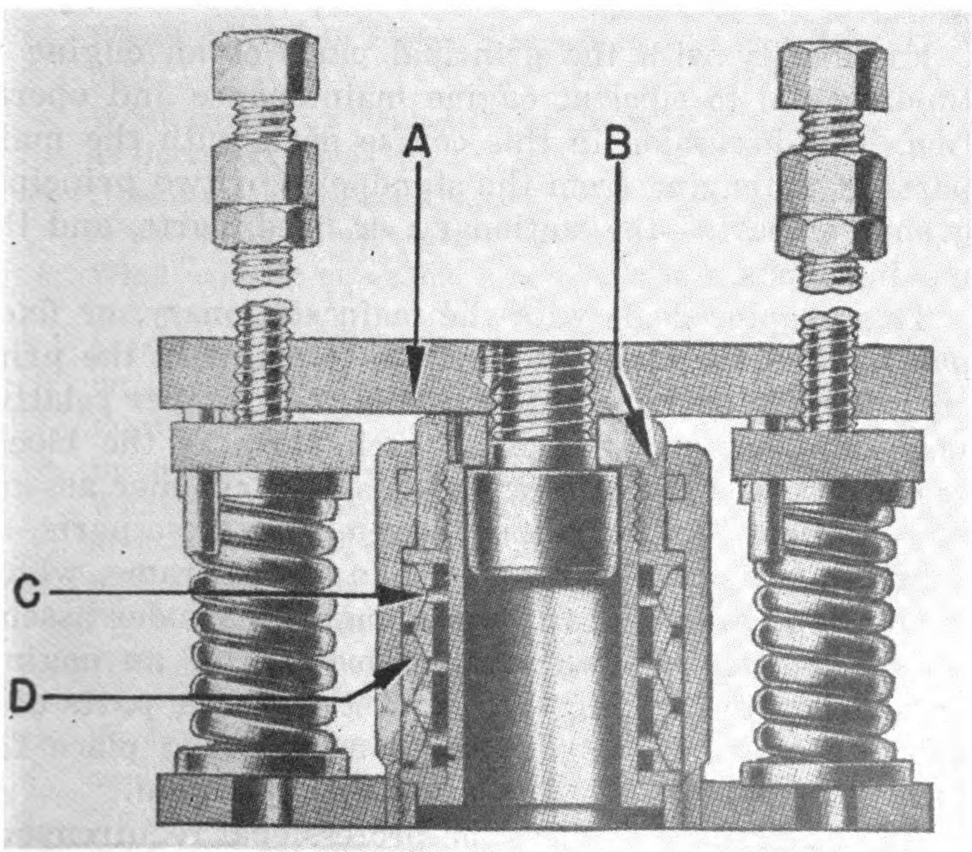


Figure 3–26.—Shock absorber.

are shown in figure 3–25. Four or more spring type isolators (A) are used to support a generator set. The flexible pad or "rubber sandwich" type isolator, shown in B, is used for mounting small Navy engines. The rubber block in the isolator shown is bonded to steel plates which are fitted for attachment to the engine and subbase.

Shock absorbers are used to absorb vibration forces which are greater than those originating in the engine. Such forces, or shock loads, may be induced by the detonation of depth charges, torpedoes, bombs, etc. The shock absorber operates on the principle of the vibration isolator but incorporates an additional device to protect the engine against severe shock loads. A common type of shock absorber in use in the Navy is illustrated in figure 3–26.

SUMMARY

Familiarity with the principal parts of an engine is fundamental to efficient engine maintenance and operation. The discussion in this course deals with the main parts of an engine from the standpoint of two principal groups of parts—the stationary, or fixed, parts, and the moving parts.

This chapter deals with the main stationary, or fixed parts, which function, as a group, to maintain the principal moving parts of the engine in their proper relative position. This group includes such parts as the block, crankcase, base, oil pan, end plates, and cylinder assemblies. Except for the cylinder assemblies, these parts, as a group, are sometimes referred to as the frame, which is the load carrying part of the engine. Cylinder assemblies complete the structural framework of an engine. In addition to forming the combustion space, parts of a cylinder assembly may serve as a mounting place for other engine parts essential to engine operation.

As you prepare to meet the professional requirements for advancement in your rating, it will be to your advantage to know as much as possible about the stationary,

or fixed, parts of an engine. You should be familiar with differences in design of these parts. You should know the function of each part and how each part is related to other parts and systems of the engine. Know the common types of materials used in the construction of the parts. All these factors and others dealing with engine parts have been pointed out in this chapter. A thorough knowledge of the fixed parts of an engine will make the discussion which follows on moving engine parts, engine systems, and engine operating and maintenance procedures more easily understood.

QUIZ

1. What is the main purpose of the principal stationary parts of an engine?
2. What are the four principal requirements which the stationary parts of a Navy marine engine must meet?
3. Which part of an engine is considered the main load-carrying part?
4. What part of an engine frame generally supports such parts as liners and heads?
5. How does en bloc construction differ from the construction of blocks found in most large engines?
6. What parts of an engine generally contain passages for cooling water when the cylinder block does not contain such passages?
7. What part of an engine serves as a housing for the crankshaft?
8. Briefly describe how crankshaft housings may differ.
9. What are the purposes of the end plates which are attached to some engine blocks?
10. Besides permitting access to internal engine parts, what other function may be performed by an access opening and cover?
11. What makes the seal between a cylinder head and block when a gasket is not used?
12. From a maintenance standpoint, why are the cylinder liners used in Diesel engines more desirable than the cylinder bore construction common to gasoline engines?
13. Why are some cylinder liners chromium plated?
14. What factor determines whether a cylinder liner is of the dry or wet type?

15. With reference to the example cited in this chapter, is it necessary (a) to enlarge cylinder bore or (b) to use a liner with a smaller diameter, when replacing press fit liners with those having a loose fit?
16. What forms the water jacket of a wet type liner which does not have integral cooling passages?
17. What factor makes it difficult to maintain a watertight seal at the ports of wet liners which use the block or a separate jacket as part of the cooling jacket?
18. Why are some liners counterbored above the upper limit of firing ring travel?
19. Cylinder heads generally form part of the combustion spaces in an engine. In what type engine is this not true?
20. In addition to forming part of a combustion space, what purpose may be served by a cylinder head?
21. Name three requirements essential in the design and material of a cylinder head.
22. Upon what two groups of parts does the seal between the head and block of most engines principally depend?
23. Why are the threads on the block end of some cylinder head studs cut to form a tighter fit than the threads on the nut end?
24. Cylinder head gaskets, regardless of design and material, have what property in common?
25. When compared to separate mountings, what is an advantage of mounting an engine and a driven unit on a common subbase?
26. Securing devices used to fasten an engine in place may be of what two general types?
27. With respect to function, what is the principal difference between vibration isolators and shock absorbers?

CHAPTER 4

PRINCIPAL MOVING PARTS OF AN ENGINE

Many of the principal parts which are mounted within the main structure of an engine are moving parts. These parts convert the power developed by combustion in the cylinder to the mechanical energy that is available for useful work at the output shaft. In order that this conversion can be made, it is necessary for reciprocating motion to be changed to rotating motion. The parts included in the conversion process, from combustion to energy output, may be divided into the following three major groups: (1) the parts which have only reciprocating motion (pistons), (2) the parts which have both reciprocating and rotating motion (connecting rods), and (3) the parts which have only rotating motion (crankshafts). Of course, other moving parts, such as valves and valve-operating mechanisms and final drives, are required for the development and transmission of power. These additional parts are covered in subsequent chapters. This chapter deals primarily with the parts in each of the major groups, and the related parts necessary for complete units or assemblies.

PISTON AND ROD ASSEMBLIES

The first two major groups of moving parts may be further grouped under the single heading of piston and rod assemblies. Such an assembly may include a piston, piston rings, piston pin, connecting rod, related bearings,

and in some cases, a piston rod and crosshead assembly. These units and the part they serve in engine operation are discussed here under separate headings.

Pistons

As one of the principal parts in the power-transmitting assembly, the piston must be so designed and must be made of such materials that it can withstand the extreme heat and pressure of combustion. Pistons must also be light enough to keep inertia loads on related parts to a minimum. The piston aids in the sealing of the cylinder to prevent the escape of gas and transmits some of the heat through the piston rings to the cylinder wall.

Pistons have been constructed of a variety of metals—cast iron, nickel cast iron, steel alloy, and aluminum alloy. Cast iron and aluminum are in most common use at the present time. Cast iron gives longer service with little wear; it can be fitted to closer clearances, and it distorts less than aluminum. Lighter weight and higher conductivity are the principal advantages of aluminum.

Cast iron is generally associated with the pistons of slow speed engines and aluminum with those of high speed engines. However, cast iron is used for the pistons of some high speed engines. In such cases, the piston walls are of very thin construction and require additional cooling.

As mentioned in chapter 2, there are two distinct types of pistons: the trunk type and the crosshead type. Pistons of the trunk type are used only in single-acting and opposed-piston engines. Crosshead pistons are used in double-acting engines and in some single-acting engines with large bores. Most marine engines of the Navy are equipped with trunk type pistons.

TRUNK TYPE PISTONS.—Pistons of this type perform a number of functions. In addition to serving as the unit which transmits the force of combustion to the connecting rod and conducts the heat of combustion to the cylinder wall, a trunk piston serves as a valve in opening and clos-

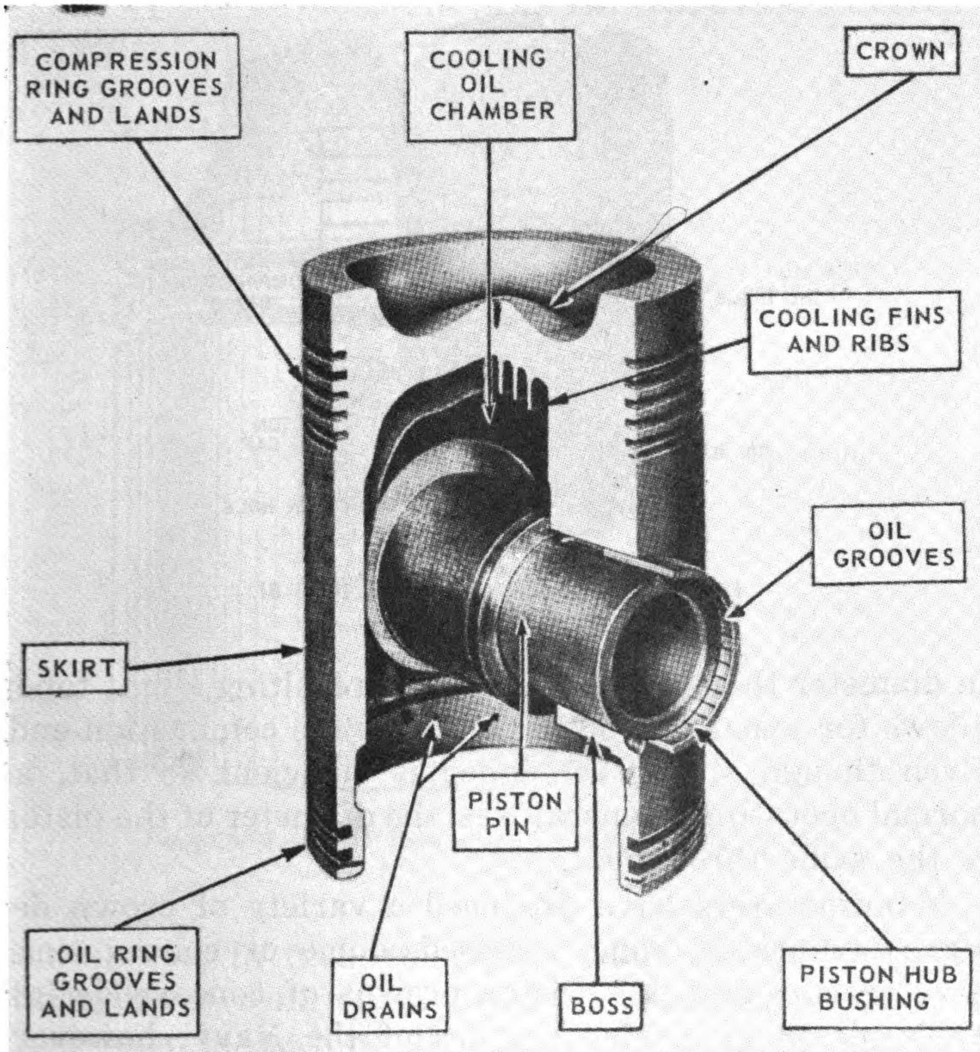


Figure 4–1.—Piston nomenclature.

ing the ports of a two-stroke cycle engine. Other functions of a piston and its parts are pointed out in the following discussion.

The nomenclature for the parts of a typical trunk type piston is given in figure 4–1. Variations in the design of trunk type pistons can be seen in figures 4–2, 4–3 and 4–4.

The CROWN or head of a piston acts as the moving surface that changes the volume of the cylinder's content (compression), removes gases from the cylinder (exhaust), and transmits the force of combustion (power). Generally, the crown end of a piston is slightly smaller

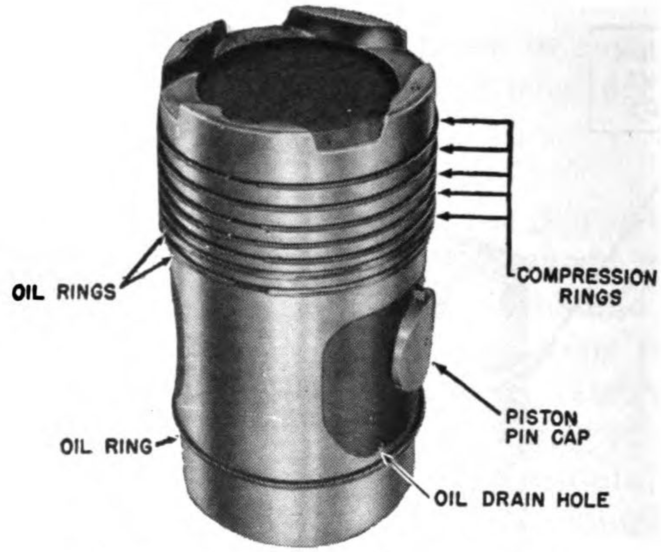


Figure 4–2.—Trunk type piston (GSB-8).

in diameter than the skirt end. The resulting slight taper allows for expansion of the metal at the combustion end. Even though slight, the taper is sufficient so that, at normal operating temperatures, the diameter of the piston is the same throughout.

Manufacturers have produced a variety of crown designs—truncated, cone, recessed, dome or convex, concave or cup, and flat. Piston crowns of concave design are common in marine engines of the Navy; however, other types may be encountered. The concave shape has the advantage of assisting in creating air turbulence, which mixes the fuel with air during the last part of compression in Diesel engines. Recesses are provided in the rim of some concave type pistons to allow room for parts which protrude into the combustion space. Examples of such parts are the exhaust and intake valves, the air starting valve, and the injection nozzle. In some two-stroke cycle engines, piston crowns are shaped with irregular surfaces which deflect and direct the flow of gases. Three of the piston crowns just mentioned are shown in figures 4–2, 4–3, and 4–4.

The SKIRT of a trunk type piston receives the side thrust created by the movement of the crank and con-

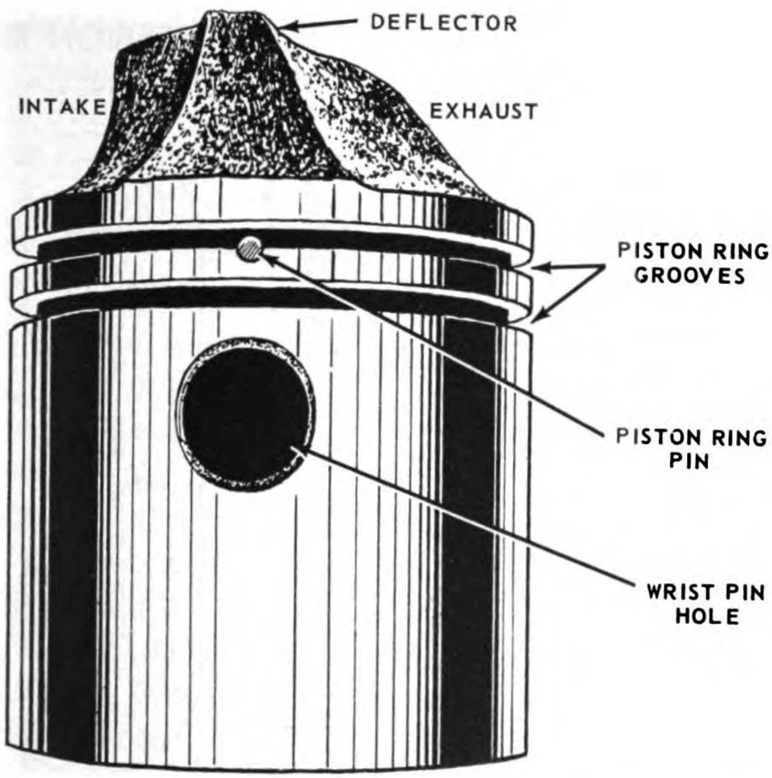


Figure 4–3.—Trunk type piston (Johnson engine, P–500).

necting rod. In turn, the piston transmits the thrust to the cylinder wall. In addition to receiving thrust, the skirt aids in keeping the piston in proper alignment within the cylinder.

Piston skirts may be of the PLAIN or smooth, the SLOTTED or split, or the KNURLED TYPES. In some cases, the plain skirt has a smooth bearing surface throughout the length of the piston. In others, the diameter of the skirt in the vicinity of the bosses is slightly less than that of the rest of the piston. (See fig. 4–2.) Pistons with slotted skirts (see fig. 4–4) are so constructed as to permit the skirt to expand without increasing the piston diameter at heavy sections. The knurled skirt is of relatively recent design. (Knurls: small beads on a metal surface.) One engine manufacturer has adopted pistons with skirts of this type to replace pistons with smooth skirts. One advantage claimed for pistons of the knurled

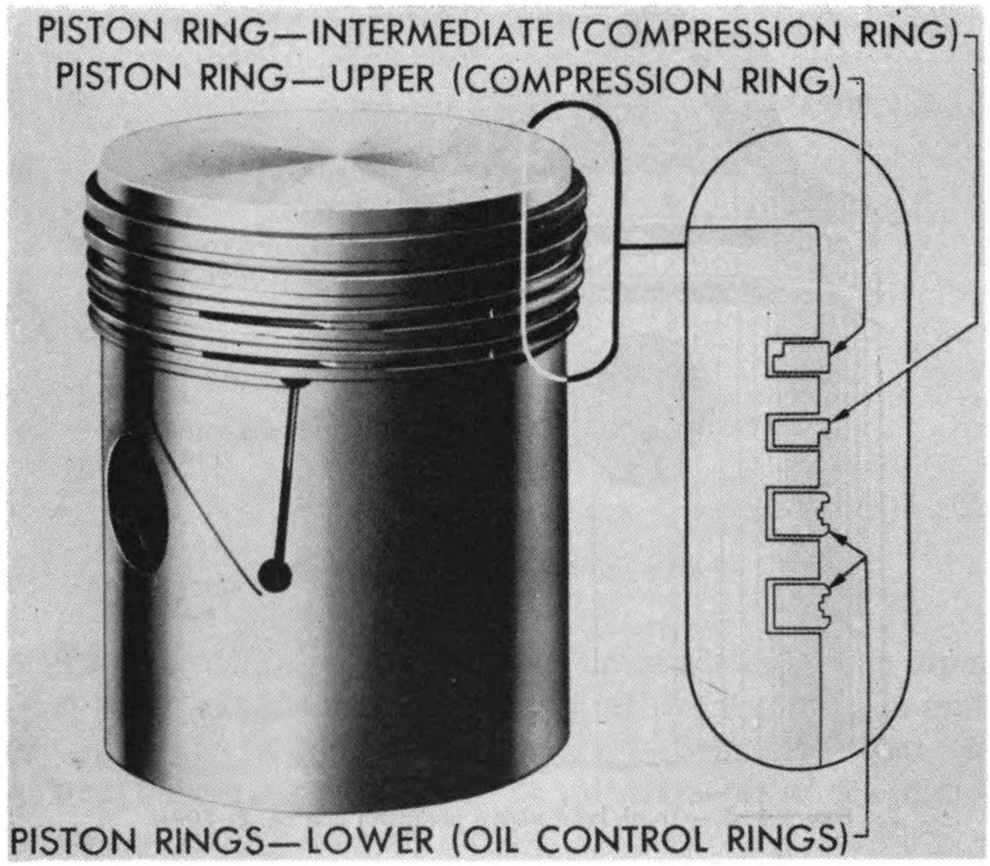


Figure 4–4.—Trunk type piston (M-8).

type is that longer service can be expected because of better lubrication afforded by the oil carried by the knurls.

In most cases, trunk type pistons are of one-piece construction; however, some trunk pistons are made of two parts and two metals. In such cases, the trunk or skirt is made of cast iron or an alloy and the crown or head is made of steel. In some pistons of this type construction, the crown is fitted to the trunk with a ground joint, while in others, the parts are welded together.

Without GROOVES AND LANDS, the piston rings could not be properly spaced nor held in position. The number of grooves and lands to be found on a piston will vary considerably, depending upon such factors as the size of the piston, the type of the piston, and the manufacturer's idea of the best design. (See figs. 4–1, 4–2, 4–3, and 4–4.)

Some pistons are constructed with OIL DRAINS (small holes) in the bottom of some of the grooves. In some cases, oil drains are located in the skirt of the piston. These holes serve as oil returns, permitting lubricating oil from the cylinder wall to pass through the piston into the crankcase. The location of the oil drains in two pistons are shown in figures 4–1 and 4–2.

Generally, the BOSSES (hubs) of a piston are heavily reinforced openings in the piston skirt. In some cases, the bosses are a part of an insert which is secured to the inside of the piston. The principal function of the bosses is to serve as mounting places for the bushings or bearings which support the wrist pin. They provide a means of attaching the connecting rod to the piston. In some cases, the bosses serve as the pin bearings. Generally, the diameter of the piston at the bosses is slightly less than the diameter of the rest of the piston. (See fig. 4–2.) This provision is necessary to compensate for the expansion of the extra metal in the bosses.

Because of the intense heat generated in the combustion chamber, adequate COOLING must be provided. The transmission of heat through the rings (approximately 30 percent of the heat absorbed by the piston) to the cylinder wall is not sufficient in many engines to keep the unit cooled within operating limits. Most pistons have fins or ribs and struts on their interior, as internal parts of the piston. (See fig. 4–1.) These parts provide additional surface for the dissipation of heat, and much of the heat is carried away by oil which may be pump forced, splashed, or thrown by centrifugal force onto the piston assembly. Oil is the principal means of cooling most piston assemblies; however, some older model engines of the larger single-acting and double-acting types made use of water as a means for cooling. Intake air is also utilized in cooling hot engine parts. In order to exhaust or scavenge a cylinder of burned gases and cool the engine parts, the intake and exhaust valves are so

timed that both valves are open for a short interval of time at the end of the exhaust stroke. This arrangement allows the intake air to enter the cylinder, clean out the hot gases, and, at the same time, cool the parts.

CROSSHEAD TYPE PISTONS.—Pistons referred to as crosshead type pistons are generally constructed as closed cylinders. The design of a crosshead piston is governed to some extent by the fact that side thrust is not received by the piston, and by the type engine in which it is used. When used in a large-bore, single-acting, four-stroke cycle engine, crosshead pistons are generally not much longer than necessary to accommodate the rings. In the case of single-acting, two-stroke cycle engines, the existence of ports in the cylinder necessitates a skirt, or extension, of the piston to prevent uncovering the ports when the piston is at TDC. The pistons in double-acting engines are built of several sections and have crowns at both ends. A piston of this type and the related parts of the piston and rod assembly are shown in figure 2–11.

While the term "trunk" is more or less descriptive of one type of piston, the term "crosshead" actually identifies a component of the piston and rod assembly. The function of the crosshead as well as of related parts of the assembly is discussed more fully in a subsequent section of this chapter.

Piston Rings

Piston rings are particularly vital to engine operation in that they must effectively perform three functions: seal the cylinder, distribute and control lubricating oil on the cylinder wall, and transfer heat from the piston to the cylinder wall. All rings on a piston perform the latter function, but two general types of rings—compression and oil—are required to perform the first two functions. There are numerous types of rings in each of these groups, constructed in different ways for particular purposes. Some of the variations in ring design are illustrated in figure 4–5.

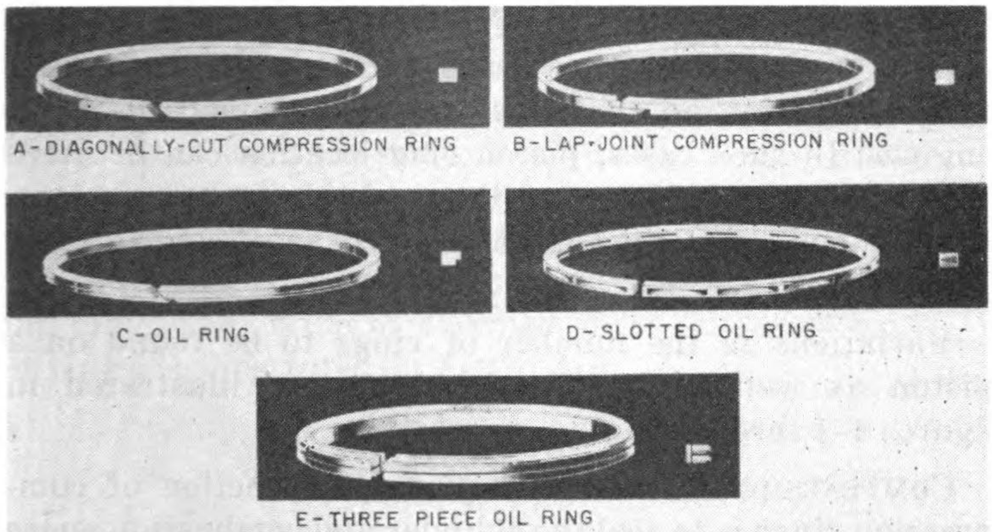


Figure 4—5.—Types of piston rings.

Rings are manufactured with several different types of end joints. Even though the straight cut (square, butt) joint is the most common, many rings are designed with diagonal (angle, miter), or step (lap) joints. (See fig. 4–5.)

The number of rings to be found on a piston will vary with the type and size of the piston. For example, a piston of the gasoline engine used to drive the P–500 pump is fitted with three rings; while a piston in a large Diesel engine may be fitted with as many as eight rings. The crosshead pistons of double-acting engines may have as many as six compression rings on each crown end.

The location of rings also varies considerably. Obviously, the compression rings would be located toward the crown or combustion end of the piston. The ring closest to the crown is sometimes referred to as the "firing" ring. In some cases, both compression and oil rings are located toward the crown, "above" the pin bosses. In other instances, the compression rings and one or two oil rings are above the bosses with one or two oil rings "below" the bosses. (The terms "above" and "below" adequately identify ring location when the crown of the piston is at the top, as is the case in engines of the vertical in-line

type or even some V-types. However, these terms may lead to confusion in some cases, such as when referring to ring location on the upper pistons of opposed-piston engines. In such cases, piston ring location can be more accurately identified by referring to the "crown or combustion end" and the "skirt or crankshaft end" of the piston.)

Variations in the number of rings to be found on a piston as well as in ring locations are illustrated in figures 4–1 through 4–4.

COMPRESSION RINGS.—The principal function of compression rings is to seal the cylinder and combustion space so that the gases within the space cannot escape until they have performed their function. Some oil is carried with the compression rings as they perform their function.

Most compression rings are made of gray cast-iron; however, some types have special facings, such as a bronze insert in a slot cut circumferentially around the ring, or a treated surface. Rings with the bronze inserts are sometimes called "gold seal" rings while those with special facings are referred to as "bimetal" rings. The bimetal ring consists of two layers of metal bonded together, the inner layer being steel and the outer being cast iron.

Compression rings have been designed with a variety of cross-sections; however, the rectangular cross-section is the most common. Since piston rings contribute as much as any other one thing toward maintaining pressure in a cylinder, they must possess sufficient elasticity to press uniformly against the cylinder walls. The diameter of the ring, before installation, is slightly larger than the cylinder bore. Because of the joint, the ring can be compressed to enter the cylinder. The tension created when the ring is compressed and placed in a cylinder causes the ring to expand and produce a pressure against the cylinder wall. The pressure exerted by rings closer to the combustion space is increased by the action of the con-

fined gases during compression and combustion. The gases enter behind the top ring, through the clearance between the ring and groove, and force the ring out against the cylinder and down against the bottom of the groove. The gas pressure on the second and other compression rings is progressively less, since the gas reaching these rings is limited to that passing through the gap of the firing ring. The action of confined gases on the compression rings is illustrated in figure 4–6.

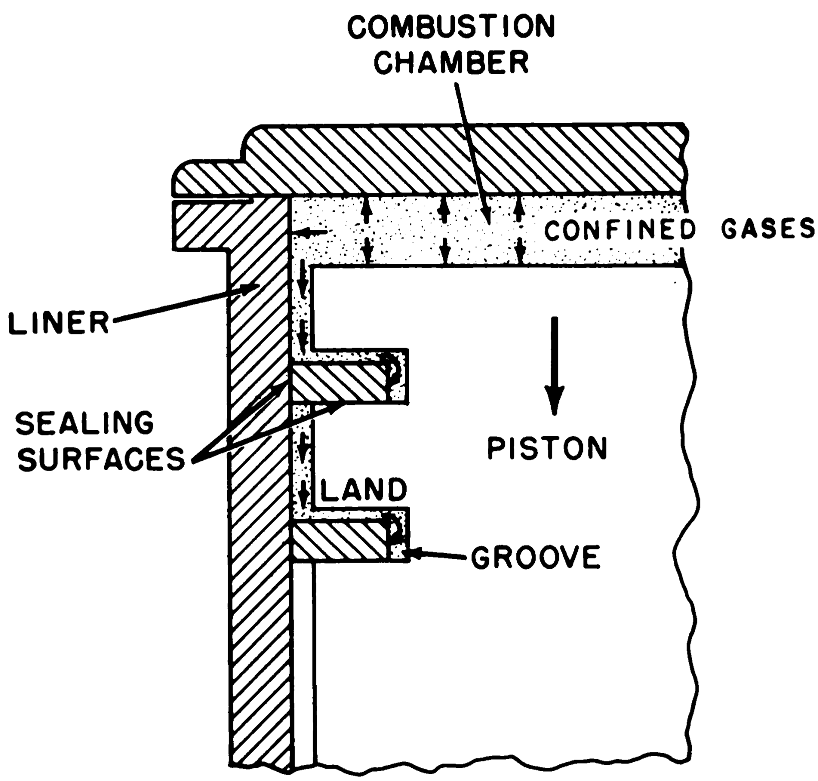


Figure 4–6.—How confined gases aid rings in sealing the combustion space.

When a piston assembly has been disassembled, visual inspection will reveal whether or not the compression rings have been functioning properly. If a ring has been working properly, the face (surface bearing against the cylinder wall) and the bottom of the ring will be bright and shiny because of contact with the cylinder wall and the groove. The top and back (inside surface) of the ring will be black, since they are exposed to the hot combustion

gases. The exposed sides and corresponding parts of the ring groove may be covered with deposits of carbon which must be removed during overhaul. Black areas on sealing surfaces will indicate that hot gases have been escaping.

Under normal operating conditions, with engine parts functioning properly, there will be very little leakage of gas, because of the excellent seal made by the ring pressure and the gas pressure. The oil which prevents metal-to-metal contact between the rings and cylinder wall also aids, to a degree, in making the seal. When a proper seal is established, the only point at which gas leakage can normally occur is through the piston ring gaps.

The gap of a piston ring is so small, compared to the total circumference of the ring, that the amount of leakage is negligible when rings are functioning properly. The time during which gas pressure is applied to the rings in a modern high-speed engine is insufficient to cause any appreciable leakage through the joints. The leakage can be held to a minimum if the rings are so placed that the joints of successive rings are on alternate sides of the piston. In most cases, no means for securing the rings is provided; however, some manufacturers use metal pins or dowels to prevent rings from shifting around in the grooves. In some cases, the ring or groove pin fits in the gap between the ends of the ring. Groove pins of this type are shown in figure 4–3.

OIL RINGS.—In performing their function, oil rings must do two things. First, they must distribute oil to all parts of the cylinder wall in sufficient quantity to prevent metal-to-metal contact. Second, the rings must control the amount of oil distributed. Without an adequate oil film between the rings and the cylinder, undue friction occurs, resulting in excessive wear of the rings and the cylinder wall. On the other hand, excess oil is as undesirable as insufficient oil. If too much oil is distributed by the rings, the oil may reach the combustion space and burn. This not only results in the waste of oil but also

causes smoky exhaust and excessive carbon deposits in the cylinder. Such carbon deposits may cause the rings to stick in their grooves. Sticking rings generally lead to a poor gas seal. Therefore, the rings must provide proper control as well as proper distribution of the lubricating oil. Rings of various designs have been constructed to take care of the problem of oil control and distribution in the cylinders of an engine. Three of these rings are shown in figure 4–5.

Various terms are used by manufacturers to identify the oil rings of an engine. Such terms as oil control, oil scraper, oil wiper, oil cutter, oil drain, oil regulating, etc., may be encountered in the various engine instruction manuals. Regardless of identifying terms, all such rings are designed to control and distribute lubricating oil within the cylinder of an engine.

If a distinction is to be made between types of oil rings, perhaps the terms "oil control" and "oil scraper" should be used. When this distinction is made, the oil control rings are considered to be those oil rings closest to the compression rings while the oil scraper or wiper rings are those farthest from the combustion end of the piston. Oil control rings function to prevent excessive amounts of oil from flowing to the compression rings, and entering the combustion space. Oil scraper rings regulate the amount of oil passing between the piston skirt and cylinder wall by wiping off the excess oil thrown into the cylinder bore by the crankshaft and connecting rod. In performing their function, the oil rings must permit sufficient oil to be carried to the upper part of the cylinder wall so that the piston and compression rings receive proper lubrication.

In general, manufacturers apply to oil rings the term which they feel best describes the function performed by the ring of their design. These terms, as well as design, vary with respect to location on any given piston. For example, a piston of a GM 6–71 has two "oil control" rings

placed on the skirt below the pin. Both rings are identical, each consisting of three pieces (two rings and an expander). The ring illustrated in (*e*) of figure 4–5 is representative of this type of ring. In rings of this type, the two "scraping" pieces have very narrow faces bearing on the cylinder wall. This permits the ring assembly to conform to the cylinder wall shape rapidly. Since the ring tension is concentrated on a small area, the rings will cut through the oil film easily and do an efficient job of removing excess oil. The bevel on the upper edge of each ring face causes the ring to ride over the oil film as the piston moves toward TDC, but as the piston moves on intake and power, the sharp, hook-like lip of each ring scrapes or wipes the oil from the cylinder wall.

Another example of differences in terminology and location is found in the FM 38D8 1/8. A piston in this type engine has three oil rings all located on the skirt end. The two nearest the crankshaft end of the piston are called oil "drain" rings while the ring nearest the pin bosses is referred to as the "scraper." The drain rings are slotted to permit oil to pass through the ring and to continue on through the holes drilled in the ring grooves. Figure 4–5(*d*) shows one type of slotted oil ring.

The oil rings of the ALCO 539 are referred to as "cutter" rings. These rings, one located "above" the pin and two on the skirt, are similar in design to the slotted rings just mentioned. The GSB–8 piston (fig. 4–2) also uses slotted oil rings, but in this case two are located above the pin, with only one on the skirt. A ring expander is used with the skirt ring to increase its pressure against the cylinder.

While the types of rings discussed here and illustrated in figure 4–5 are representative of many rings now in use, other variations exist. One such variation in cross-sectional design is shown in figure 4–4. Other variations in piston ring design are given in NavPers 16178A, *Fundamentals of Diesel Engines,* chapter 7.

Piston Pins and Pin Bearings

In trunk type piston assemblies, the only connection between the piston and the connecting rod is the pin (sometimes referred to as the wrist pin) and its bearings. These parts must be of especially strong construction because the power developed in the cylinder is transmitted from the piston through the pin to the connecting rod. The pin is the pivot point where the straight-line or

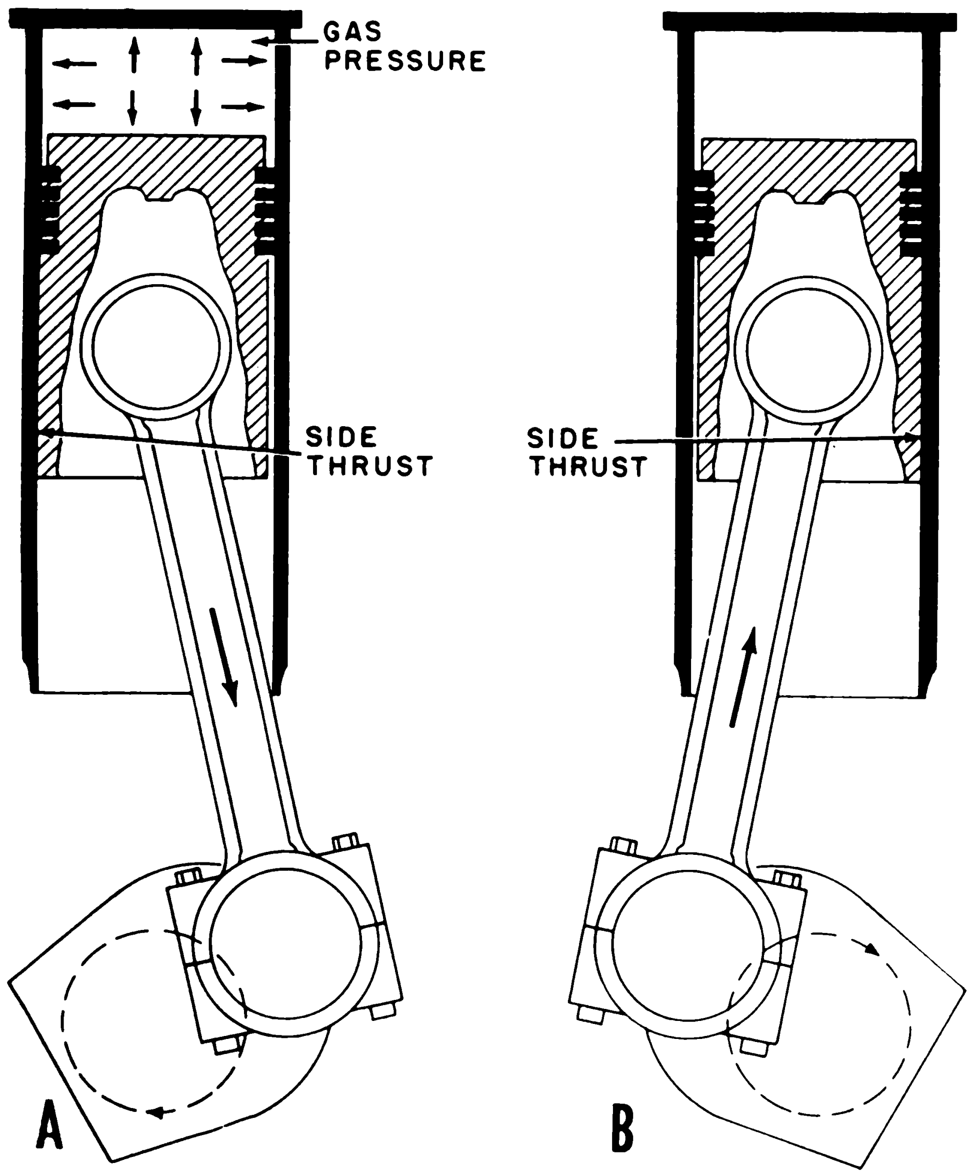


Figure 4—7.—Side thrust—trunk type piston, single-acting engine.

reciprocating motion of the piston changes to the reciprocating and rotating motion of the connecting rod. Thus, the principal forces to which a pin is subjected are the forces created by combustion and the side thrust created by the change in direction of motion. Before discussing the pin further, let us consider the side thrust which occurs in a single-acting engine equipped with trunk type pistons. (See fig. 4–7.)

Side thrust is exerted at all points during a stroke of a trunk type piston, except at TDC and BDC. This side thrust is absorbed by the cylinder wall. Thrust occurs first on one side of the cylinder and then on the other, depending upon the position of the piston and the rod and the direction of rotation of the crankshaft. In figure 4–7A, gas pressure is forcing the piston downward (power). Since the crankshaft is rotating clockwise, the force of combustion, and the resistance of the driven parts tends to push the piston to the left. The resulting side thrust is exerted on the cylinder wall. If the crankshaft were rotating counterclockwise, the situation would be reversed.

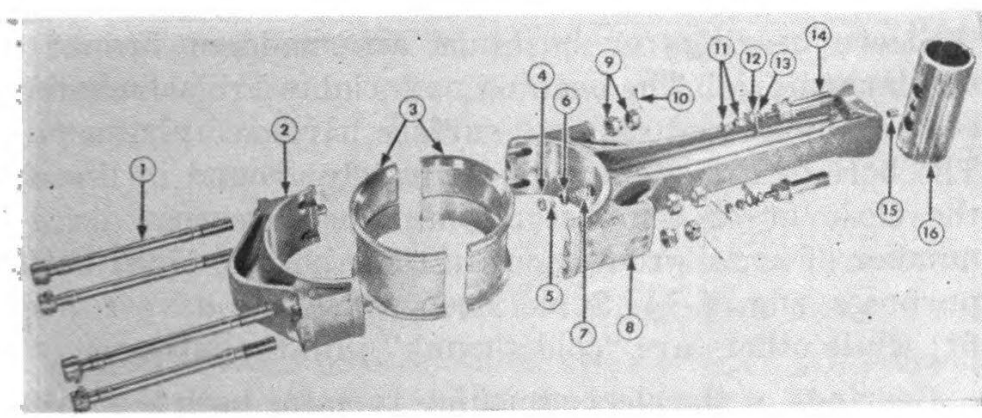
In B of the illustration, the piston is being pushed up (compression) by the crankshaft and connecting rod. This causes the side thrust to be exerted on the opposite side of the cylinder. Thus, the side thrust alternates from side to side as the piston moves up and down. Side thrust in an engine cylinder makes proper lubrication and correct clearance essential. Without an oil film between the piston and cylinder wall, metal-to-metal contact occurs and results in excessive wear. If clearance between piston and cylinder wall is excessive, a pounding noise, called PISTON SLAP, will occur as the thrust alternates from side to side.

PISTON PINS.—Pins are usually hollow and made of alloy steel, machined, hardened, and precision ground and lapped to fit the bearings. In some cases, pins are chromium-plated to increase the wearing qualities. Their construction provides maximum strength with minimum weight. Lubrication is provided by splash from the crank-

case or by oil forced through drilled passages in the connecting rods.

Piston pins must be secured in position so that they do not protrude beyond the surface of the piston, or have excessive end-to-end motion. Otherwise the pin would tend to damage the cylinder wall. Piston pins may be secured in a piston and rod assembly in one of three ways: (1) rigidly fastened into the piston bosses, (2) clamped to the end of the rod, or (3) free to rotate in both piston and rod. When piston pins are secured by these methods, the pins are identified as: (1) stationary (fixed), (2) semifloating, and (3) full-floating, respectively.

The STATIONARY pin is secured to the piston at the bosses and the connecting rod oscillates on the pin. Since all movement is by the connecting rod, there may be uneven wear on the contacting surfaces in this type installation. Pins of the SEMIFLOATING type are secured in the middle to the connecting rod. (See fig. 4–8.) In this case, the ends of the pin are free to move in the piston-pin



1. Connecting Rod Bolt
2. Cap
3. Bearing Shell
4. Check Valve Seat
5. Check Valve
6. Check Valve Sleeve
7. Check Valve Spring
8. Connection Rod
9. Drake Nut
10. Cotter Pin
11. Drake Nut
12. Lock Plate
13. Star Washer
14. Piston Pin Bolt
15. Dowel
16. Piston Pin

Figure 4–8.—Connecting rod assembly with semifloating piston pin (GSB-8).

bearings in the bosses. FULL-FLOATING pins are not secured to either the piston or the connecting rod. Pins of this type may be held in place by caps, plugs, and snap rings or spring clips (lock wire), which are fitted in the bosses. The securing devices for a full-floating pin permit the pin to rotate in both the rod and the piston-pin bosses. The full-floating piston pin is the most common of the three types.

PISTON-PIN BEARINGS.—The bearings used in connection with piston pins are of three types: the integral bearing, the sleeve bearing or bushing, and the needle type roller bearing. These bearings may be further identified according to location—the PISTON-BOSS PISTON-PIN BEARINGS and the CONNECTING-ROD PISTON BEARINGS.

The bearings in the bosses (hubs) of most pistons are of the sleeve bushing type. However, in a few cases, the boss bearings are an integral part of the piston. In such cases, the bearing surface is precision bored directly in the bosses. Pistons fitted with stationary piston pins require no bearing surfaces in the bosses.

Sleeve bearings or bushings are made of bronze or similar material. The bushing material is a relatively hard bearing metal and requires surface hardened piston pins. The bore of the bushing is accurately ground in line for the close fit of the piston pin. Most bushings have a number of small grooves cut in their bore for lubrication purposes (fig. 4–1). Some sleeve bushings have a press fit; while others are "cold shrunk" into the bosses.

Bearings of the sleeve bushing type for both the bosses and the connecting rod are shown in figure 4–9. Note that the bosses are a part of an insert.

If the piston pin is secured in the bosses (stationary) of the piston or if it floats (full floating) in both the connecting rod and piston, the piston end of the rod may be fitted with a sleeve bushing or a needle bearing. Pistons fitted with semifloating pins require no bearing at the rod. (See fig. 4–8.)

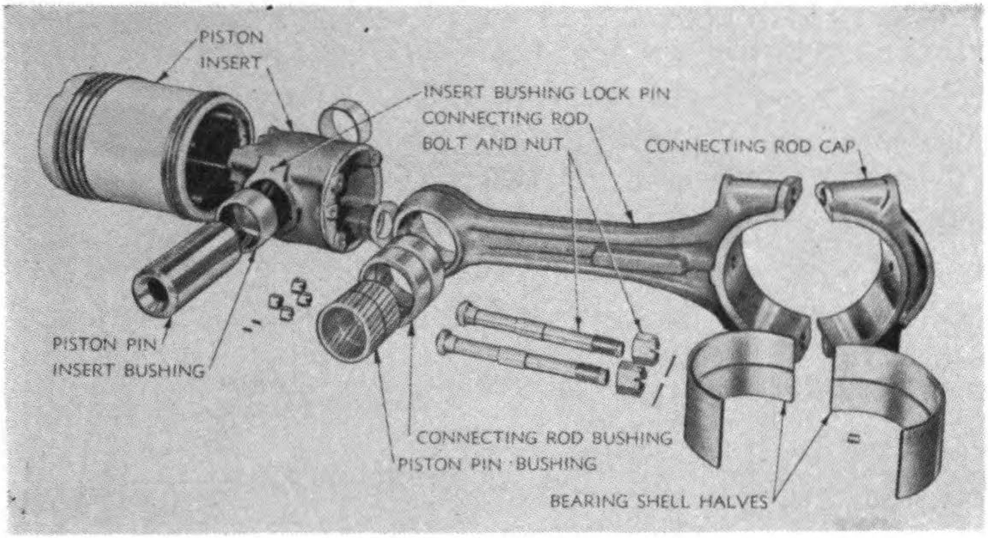


Figure 4–9.—Piston and rod assembly with sleeve bushing type bearings (FM38D8 1/8).

Sleeve bushings used in the piston end of connecting rods are similar in design to those used in piston bosses. (See fig. 4–9.) Generally, bronze makes up the bearing surface. In some cases, the bearing surface is backed with a case-hardened steel sleeve and has a shrink fit in the rod bore. In other cases, the bushing fit is such that a gradual rotation (creep) takes place in the eye of the connecting rod. In another variation of the sleeve type bushing, a cast bronze lining is pressed into a steel bushing in the connecting rod. In some engines which use full floating piston pins, the steel-backed bronze bushing rotates freely inside the piston end of the connecting rod.

Even though most engines are equipped with bushing type bearings, some have been fitted with piston-pin connecting-rod bearings of the needle roller type. An example of this type installation is shown in figure 4–10. In bearings of the type shown, the inner race is formed by the case-hardened steel piston pin. The outer race for the bearing is formed by the case-hardened steel bushing that fits in the connecting rod.

Needle bearings can be fitted with less clearance and they have less friction than bushing type bearings. How-

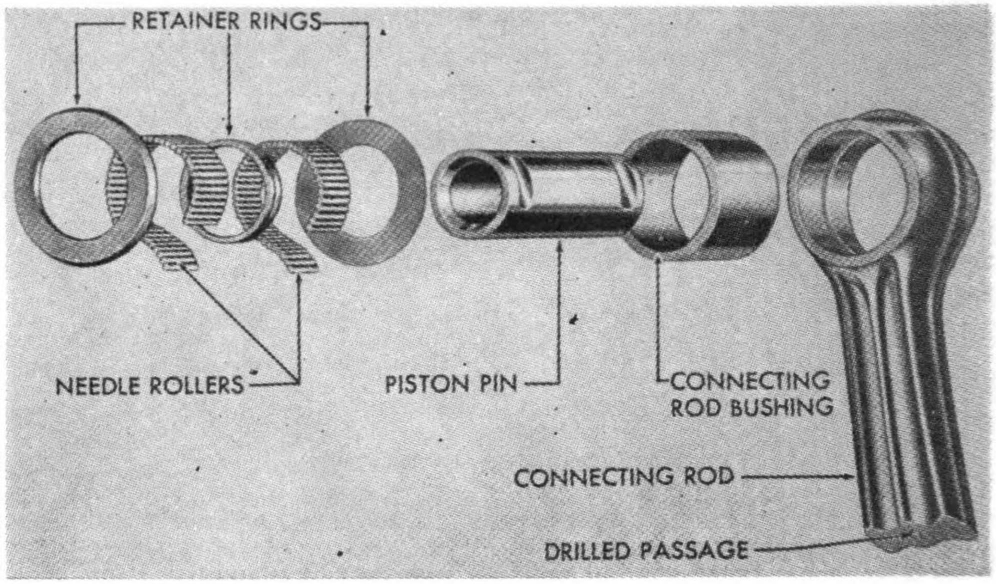


Figure 4–10.—Needle type piston-pin connecting-rod bearing assembly.

ever, needle bearing service life is shorter than that of bushings and because of the simpler construction, bushings are easier to install. For these reasons, bushing type bearings have been used in several cases as replacements for needle bearings.

Connecting Rods

The rod serves as the connecting link between the piston and crankshaft or the crankshaft and the crosshead. In order that the forces of combustion be transmitted to the crankshaft, the rod changes the reciprocating motion of the piston to the rotating motion of the crankshaft. In general, the type of connecting rod used in an engine will depend upon cylinder arrangement and the type of engine.

Several types of connecting rods have been designed; however, only four of those likely to be found in marine engines of the Navy are discussed here. To distinguish between types of rods, the following terminology will be used in this discussion: CONVENTIONAL rod, FORK and BLADE rod, PADDED rod, and FORKED rod.

CONVENTIONAL ROD.—This type of rod is sometimes referred to as the "normal" or "standard" rod because

of its extensive use by many manufacturers and its similarity to the rods used in many automobiles. Examples of the conventional rod are shown in figures 4–8 and 4–9. The rods illustrated are typical of those used in engines of the single-acting in-line and double-acting types. Rods of this type are also used in opposed piston engines and in some V-type engines. When used in V-type engines, two rods are mounted on a single crank pin. The two cylinders served are offset so that the rods can be operated side-by-side.

Rods are generally made of drop forged heat-treated carbon steel (alloy steel forging). In most cases, the rods have an "I" or "H" shaped cross-section which provides maximum strength with minimum weight. The bore (hub, eye) at the piston end of the rod is generally forged as an integral part of the rod (see figs. 4–7, 4–10, and 4–11); however, the use of semifloating piston pins eliminates the need for this bore. (See fig. 4–9.) The bore at the crankshaft end is formed by two parts, one an integral part of the rod and the other a removable CAP. (See figs. 4–8, 4–9, and 4–11.) Rods are generally drilled or bored to provide an oil passage to the piston end of the rod.

The bore at the crankshaft end of a conventional rod is generally fitted with a precision bearing of the shell type. (See figs. 4–8 and 4–9.) In design and materials, rod bearings are similar to the main journal bearings which are discussed in connection with crankshafts later in this chapter. Even though the rod bearings of most engines are of the shell type, roller type bearings are used in some

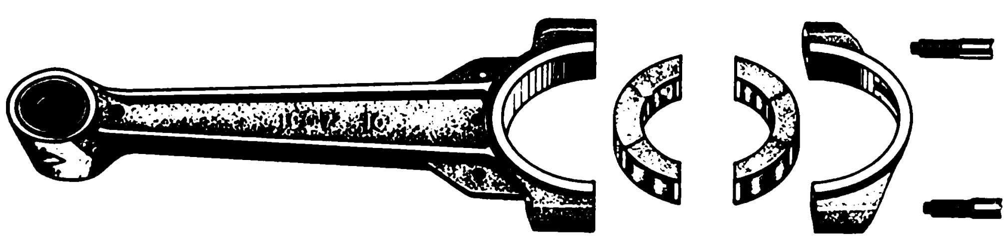


Figure 4–11.—Connecting rod assembly with roller type bearing (Johnson, P–500).

relatively small engines. An example of a roller type rod bearing is shown in figure 4–11.

Connecting rod bearings of most engines are pressure lubricated by oil from adjacent main bearings, through drilled passages or connecting external tubes. The oil is evenly distributed over the bearing surfaces by oil grooves in the shells. Bearing shells are provided with drilled holes which line up with an oil groove in the rod bearing seat. Oil from this groove is forced to the piston pin through the drilled passage in the rod.

FORK AND BLADE (PLAIN) CONNECTING RODS.—While two conventional rods are used to serve two cylinders in some V-type engines, a single assembly consisting of two rods is used in other engines of this type. As the name implies, one rod is fork-shaped at the crankshaft end to receive the "blade" rod. In general, fork and blade rods are similar to conventional rods in material and construction. However, design at the crankpin end obviously differs from that of the conventional rods. (See fig. 4–12.)

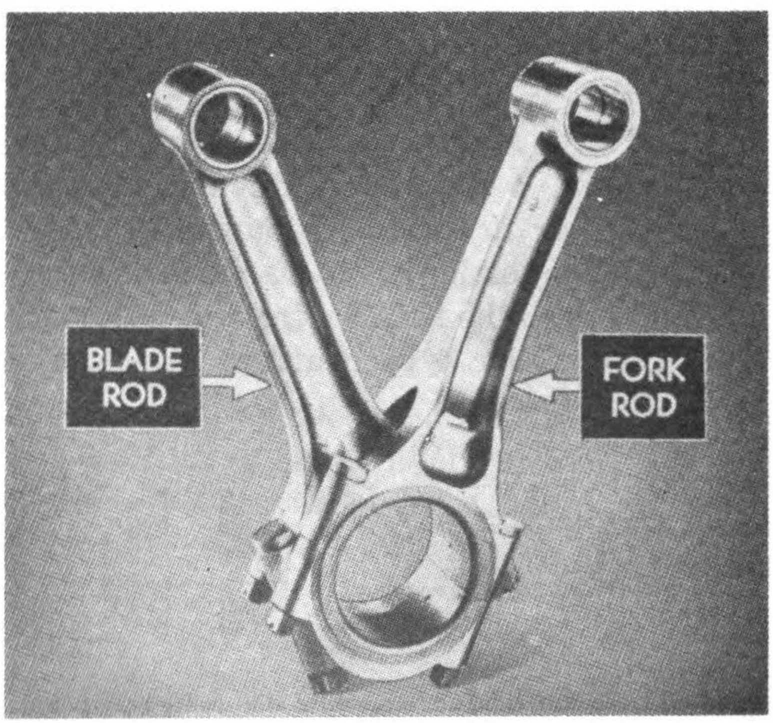
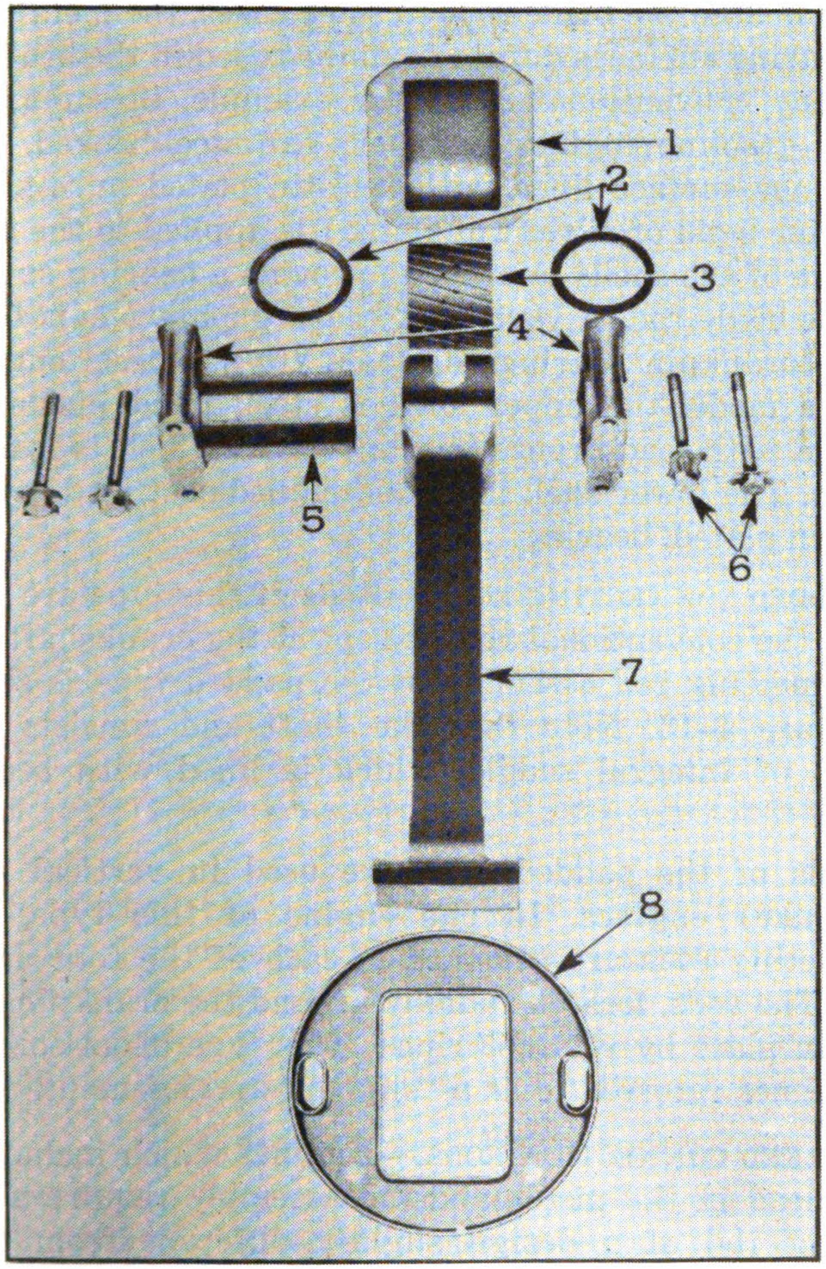


Figure 4–12.—Fork and blade connecting rod (Packard).



1. Piston cooling oil baffle
2. Piston pin bushing retaining rings
3. Piston pin bushing
4. Trunnions
5. Piston pin
6. Cap screws
7. Connecting rod
8. Thrust plate

Figure 4–13.—Padded type connecting rod assembly (GM16–184A).

The bearings of fork and blade rods are similar to those already discussed, except that, in this case, the shells must have a bearing surface on the outer surface to accommodate the blade rod. In some cases, the metal used for bearing surfaces differs from that used in the bearings of many conventional rods. For example, in some high speed, gasoline engines the shells are steel-backed, with the inner surface lined with lead-tin plated pure silver. A center band of silver (unplated) is applied to the outer surface of the shells in order to provide a bearing surface for the blade rod. A variety of bearing materials is found in the crankpin bearings of some V-type Diesel engines. In one model the upper shell is steel, lined inside and outside with lead-bronze bearing metal which is lead-tin plated. The lower shell is a solid chilled cast lead bronze, lead-tin plated, bearing.

PADDED CONNECTING RODS.—Rods of this type are similar to the conventional rods except at the crankshaft end. A connecting rod assembly of the padded type is shown in figure 4–13. Note that the shaft end consists of a "pad" or integral saddle, which is lined with bearing metal.

Rods of the padded type are used in vertical shaft (pancake) engines. In one engine of this type, four connecting rods are attached to each of the four crankpins. The rods, located radially around the crankpins, are held in place by retainer rings. This type of assembly is sometimes referred to as a "slipper" arrangement.

FORKED CONNECTION RODS.—Engines which include the crosshead in the piston-and-rod assembly require a connecting rod of a design slightly different from those already discussed. The rod is fork-shaped at the upper end to accommodate the piston rod and crosshead connection. Each side of the fork has a bore, similar to the piston-pin bore of the conventional rod. The rod is secured to the crosshead assembly by, and pivots upon, the crosshead (wrist) pin. (See figs. 4–14 and 4–16.)

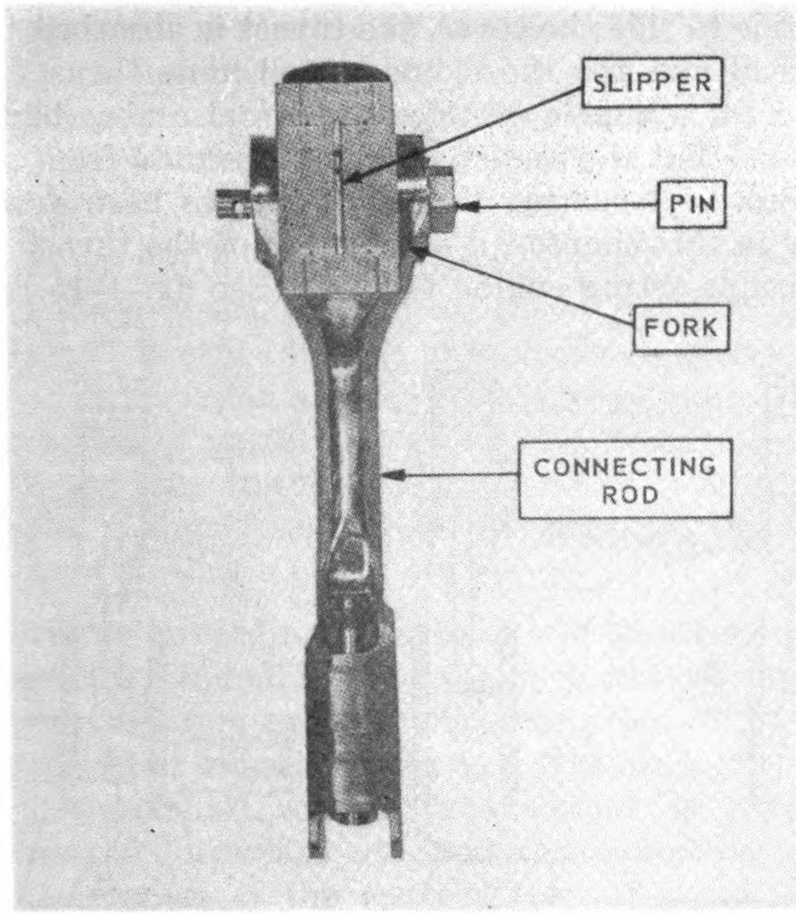


Figure 4–14.—Forked type connecting rod with crosshead (Hamilton).

The forked rod illustrated is of hollow tubular construction, but does not provide a passage for lubricating oil. The crosshead pin bushing receives its lubrication from the piston cooling oil supplied from the oil header through a linkage attached to the hollow crosshead pin.

Crossheads and Piston Rods

Most marine engines in Navy service use the trunk type piston connected directly to the connecting rod. However, some large-bore, single-acting engines use crosshead assemblies in connection with trunk type pistons. Crosshead assemblies are always used in the piston-and-rod assemblies of double-acting engines.

In single-acting engines where a crosshead is used in connection with a trunk type piston, side thrust alternates

from side to side; however, the thrust is absorbed by the crosshead and not the cylinder wall. Side thrust in the cylinder of a double-acting engine is also absorbed by a crosshead, but the thrust does not alternate from side to side. Since alternating thrust action has been described earlier in this chapter, a description of the thrust action in a double-acting engine follows. (See fig. 4–15.)

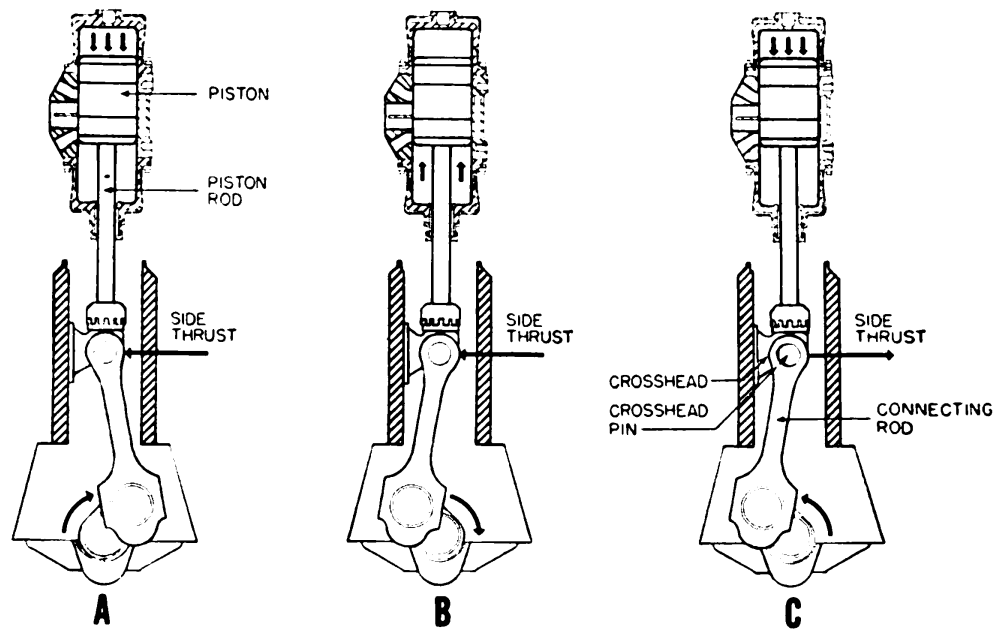


Figure 4—15.—Side thrust in the cylinder of a double-acting engine.

Since combustion takes place first on one end of the piston and then the other in a double-acting engine, a piston rod must be used to transmit the reciprocating motion to the connecting rod. A stuffing box is required where the rod passes through the cylinder, to seal the lower combustion space. As the connecting link between the piston rod and the connecting rod, the crosshead assembly guides the piston rod along the vertical axis of the cylinder and absorbs the side thrust.

As combustion occurs in the upper space, the piston is forced down. (See A of fig. 4–15.) Since the crankshaft and other driven parts as well as compression in the lower space offer resistance to the force of combustion, there is

a tendency for the bottom of the piston rod and the crosshead to be pushed to the left. The resulting side thrust is exerted on the crosshead guide by the crosshead instead of on the cylinder wall by the piston, as shown in A of figure 4–7.

In B of the illustration, combustion has taken place in the lower space, driving the piston up. Note that the crankshaft is still rotating in a clockwise direction. The force of combustion and the resistance of the parts place the connecting parts in tension. This tension causes the side thrust to be in the same direction as in the preceding example. Compare this with the situation shown in B of figure 4–7.

From the preceding discussion and illustration, it can be seen that, in double-acting engines, side thrust acts in only one direction as long as the direction of rotation of the crankshaft remains unchanged. The clockwise rotation of this crankshaft, as illustrated, might be compared to the "ahead" direction of crankshaft rotation in a reversible engine. If the engine is reversed for "astern" operation, the crankshaft rotates in a counterclockwise direction. Thus, "astern" operation of a reversible engine results in a reversal of side thrust conditions. Side thrust is exerted in a direction opposite to that in which it was exerted when the crankshaft was rotating in a clockwise direction. (See C of fig. 4–15.) This reversal in direction of side thrust makes a secondary guide necessary. The secondary guide consists of two Z-shaped sections of forged steel. These sections are commonly called the crosshead guide gibs. The gibs are bolted to the crosshead guide. (See fig. 2–11.)

Now that the purpose and principles of the crosshead and related parts are covered, let's consider the crosshead piston-and-rod assembly of a particular engine. Even though the complete piston-and-rod assemblies vary to a degree between different engines, all crossheads are similar in construction; and their purpose and principles

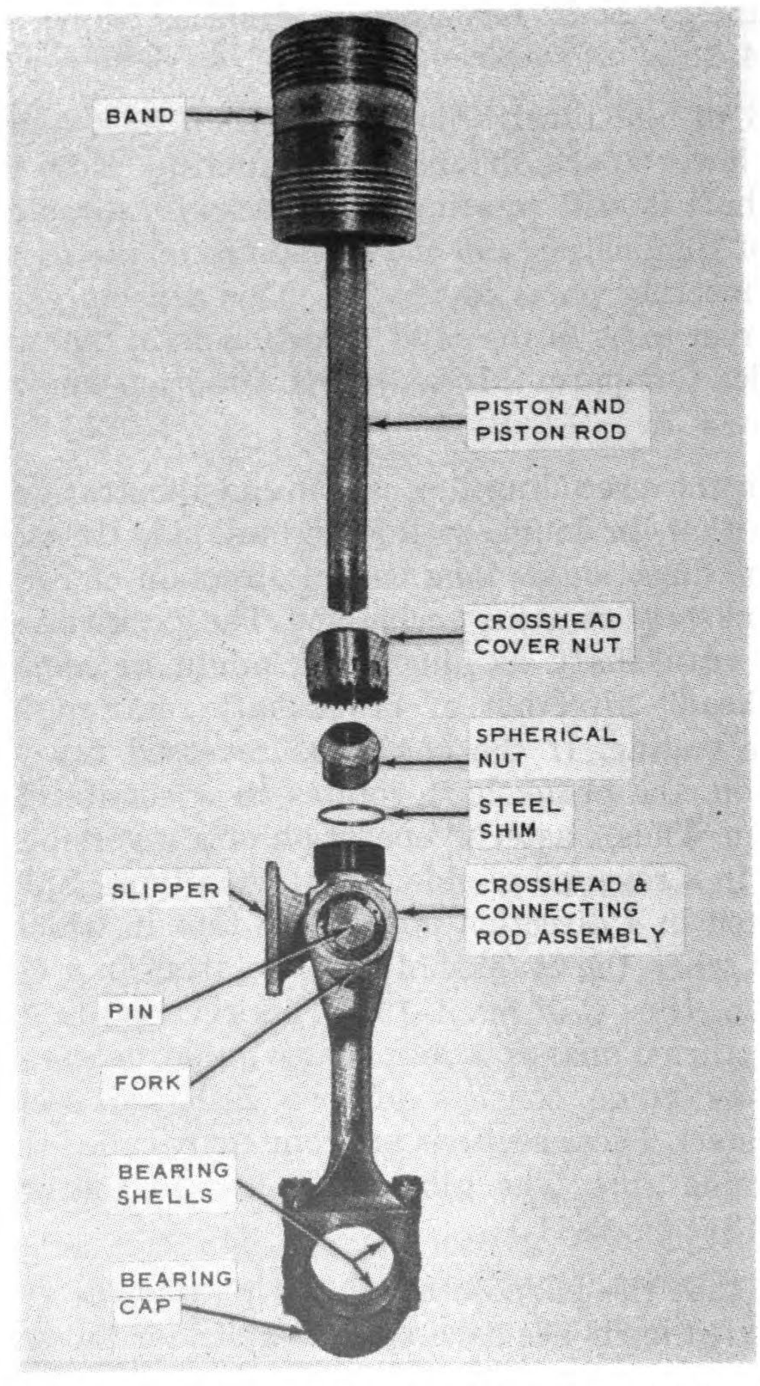


Figure 4–16.—Crosshead piston and rod assembly (Hamilton).

of operation are fundamentally the same. The assembly of a Hamilton double-acting, reversible engine is discussed in the following paragraphs. (See fig. 4–16.)

The crosshead, sometimes called the head or block, is made of forged steel. The bearing surfaces (slipper) are lined with babbitt. As an integral part of the crosshead, the slipper slides between the crosshead guide and gibs as the engine operates. The guide, a steel casting, forms an oil-tight fit with the main housing; the forged steel gibs are bolted to the guide. (See fig. 2–11.)

A hollow, tapered pin connects the forged steel connecting rod and the crosshead. This pin rides the bushings of the forked end of the rod and the two-piece, bronze, pin bushing. Each half of the pin bushing has a press fit in the crosshead.

The crosshead is connected to the piston rod by a ball-and-socket assembly. This type connection compensates for any misalignment between the parts of the piston-and-rod assembly. A connection of this nature not only allows some flexibility in the assembly but also permits the piston to rotate. Piston rotation aids in the proper distribution of oil to all parts within the cylinder. The piston rotates slowly as a result of the flow of cooling oil through spiral fins within the piston rod and piston.

The piston rod in this assembly is of forged steel. It is hollow-drilled, which permits a large supply of coolant to be circulated to and from the piston crown.

CRANKSHAFTS AND FLYWHEELS

One of the principal engine parts which has only rotating motion is the crankshaft. In some engines, a flywheel is also one of the principal moving parts. Since the flywheel is mounted on the crankshaft, both are considered here. Related items such as shaft bearings and vibration-restricting devices must also be considered in connection with these parts, in order to complete our consideration of the mechanism which converts the force of combustion into useful work.

Crankshafts

As one of the largest and most important moving parts in an engine, the crankshaft changes the movement of the piston and the connecting rod into the rotating motion required to drive such items as reduction gears, propeller shafts, generators, pumps, etc.

As the name implies, the crankshaft consists, usually, of a series of cranks (throws) formed as offsets in a shaft. As a result of its function, the crankshaft is subjected to all the forces developed in an engine. Because of this, the shaft must be of especially strong construction and is usually machined from forged alloy or high-carbon steel. The shafts of some small engines are made of cast iron alloy. Forged crankshafts are nitrided—heat treated—to increase the strength of the shafts and to minimize wear.

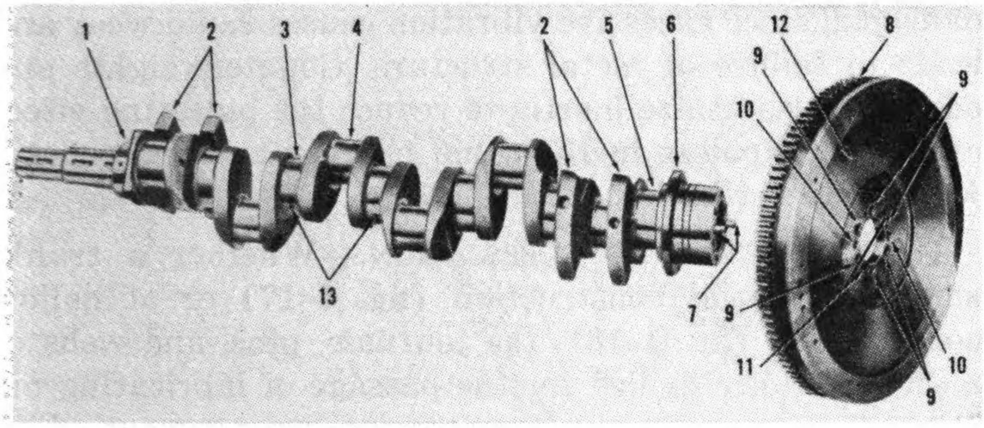
While crankshafts of a few larger engines are of the built-up type (forged in separate sections and flanged together), the crankshafts of most modern engines are of the one-piece type construction. A shaft of this type is shown in figure 4–17.

CRANKSHAFT TERMINOLOGY.—The parts of a crankshaft may be identified by various terms; however, those shown in figure 4–17 are common in the instruction books for most of the engines used by the Navy.

The MAIN JOURNALS serve as the points of support and as the center of rotation for the shaft. As bearing surfaces, the journals (crankpin and main) of most crankshafts are surface-hardened in order that a longer-wearing, more durable bearing metal can be used without causing excessive wear of the shaft.

As illustrated in figure 4–17, crankshafts have a main journal (1 and 5) at each end of the shaft. In most cases, there is an intermediate main journal (3) between the cranks; however, in the case of small shafts, intermediate journals may not be used.

Each CRANK (THROW) of a shaft may be thought of as consisting of three parts, two WEBS and a PIN. Crank webs are sometimes called cheeks or arms. The cranks or throws



1. Main Bearing Journal—Front.
2. Counterweight.
3. Main Bearing Journal—Intermediate.
4. Connecting Rod Journal—No. 3.
5. Main Bearing Journal—Rear.
6. Bolting Flange—Timing Gear.
7. Dowel—Flywheel.
8. Ring Gear.
9. Retaining Bolt Hole.
10. Dowel Hole.
11. Puller Screw Hole.
12. Flywheel.
13. Lubricating Oil Holes.

Figure 4—17.—One-piece six-throw crankshaft with flywheel.

provide points of attachment for the connecting rods as well as serve as the connecting links between main journals.

In many crankshafts, especially in large engines, the crankpins and main journals are of hollow construction. Hollow construction not only reduces weight considerably but also provides a passage for the flow of lubricating oil. (See fig. 4–18.)

In some cases, part of the webs of a crankshaft extend beyond the main journals to form or to support COUNTERWEIGHTS or DAMPERS. These devices may be integral parts of the webs (see fig. 4–17) or they may be separate units attached to the webs by studs and nuts.

Counterweights balance the off-center weight of the individual cranks and thereby hold in equilibrium the centrifugal force generated by each rotating crank. Without such balance, severe vibration will be created by crank action, particularly at higher speeds. If such vibrations are not controlled, the shaft is likely to become

damaged, since excessive vibration causes rapid wear and leads to failure of metal structure. Counterweights and dampers also utilize inertia to reduce the pulsating effect of power impulses in the same manner as the flywheel, which is described in this chapter.

CRANKSHAFTS AND LUBRICATION.—Whether a crankshaft is of solid construction (fig. 4–17) or of hollow construction (fig. 4–18), the journals, pins, and webs of most shafts are drilled for the passage of lubricating oil. Two other variations in the interior arrangement of oil passages in crankshafts are shown in figure 4–19.

A study of the two oil passage arrangements will give you an idea of the part the crankshaft plays in engine lubrication. In the system illustrated in A, each oil passage is drilled through from a main bearing journal to a crankpin journal. The oil passages are in pairs which crisscross each other in such a way that the two oil holes for each journal are on opposite sides of the journal. These holes are in axial alignment with the oil grooves of the bearing shells when the shells are in place. Since the oil groove in a bearing goes at least half way around the bearing, a part of the groove will always be aligned with at least one of the holes.

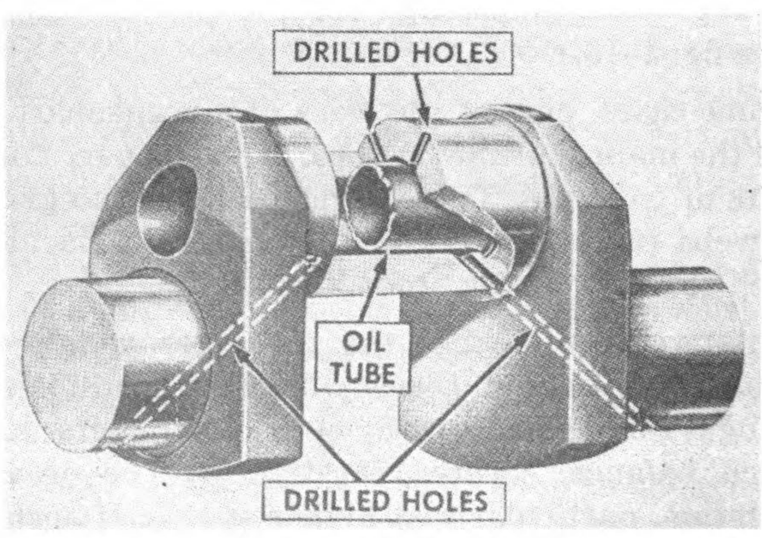


Figure 4—18.—An example of hollow crankpin construction. (GSB—8).

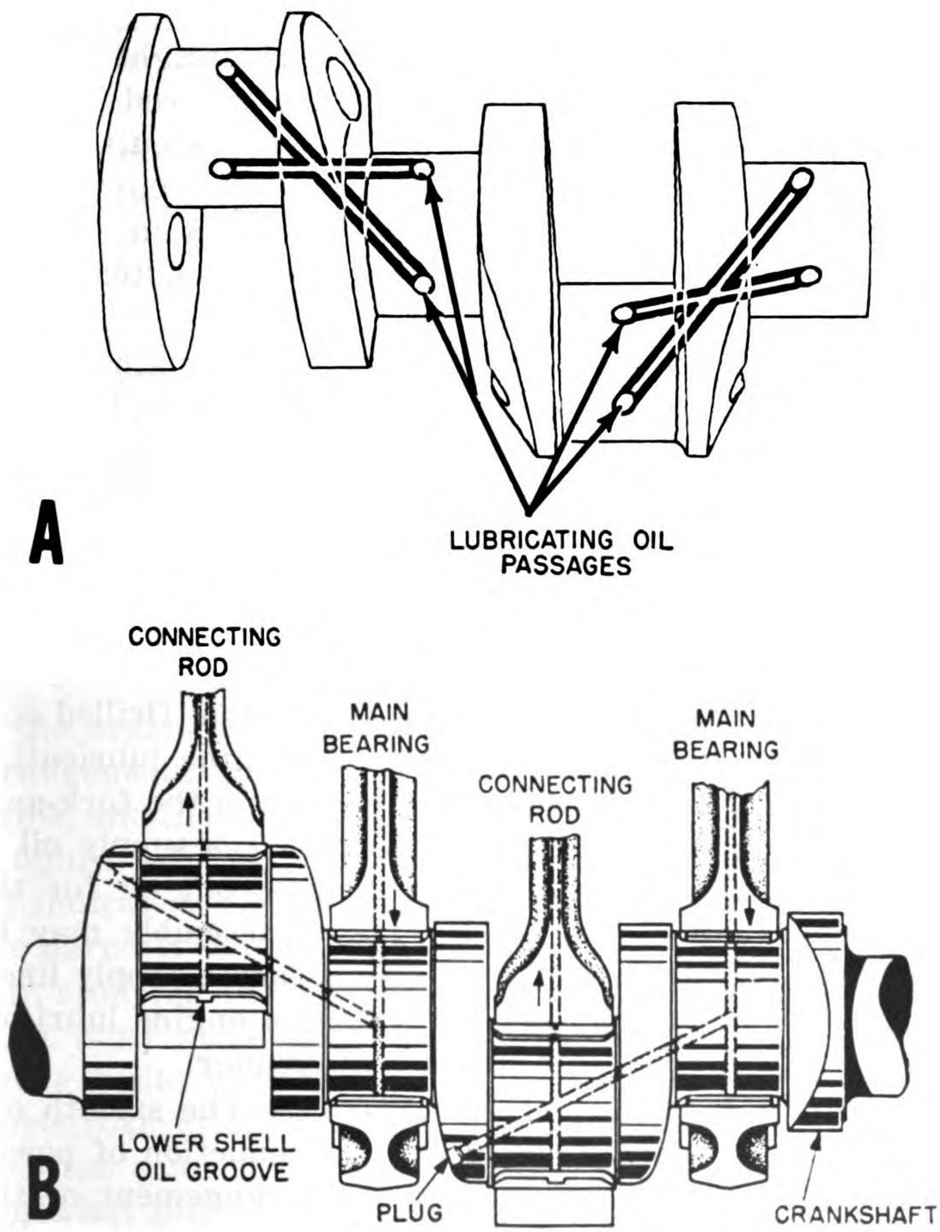


Figure 4–19.—Examples of crankshaft oil passage arrangement.

Lubricating oil under pressure enters the main bearing oil grooves. This oil lubricates the main bearings and flows on through the drilled oil passages to the crankpin bearings. From the pin bearings, the oil is forced through the drilled passage in the connecting rod to lubricate the piston pin bearing and to be forced onto the interior surface of the piston crown for cooling.

In the oil passage arrangement shown in B (shaft is shown in fig. 4–17), the passage is drilled straight through the diameter of each main and connecting rod journal. A single diagonal passage is drilled from the outside of a crankpin web to the center of the next main journal. The diagonal passage connects the oil passages in the two adjoining crankpin and main journals. The outer end of the diagonal passage is plugged.

Lubricating oil under pressure enters the main bearing and is forced through the diagonal passage to lubricate the connecting rod bearing. From there it flows through the drilled connecting rod to lubricate the piston pin and cool the piston.

In engines which use crankshaft oil passage arrangements like those just discussed and like that shown in figure 4–18, the connecting rods are drilled to carry the lubricating oil to the piston pins and piston. Drilled connecting rods are not common to all engine lubricating systems. In some V-type engines which use the fork-and-blade type connecting rod, drilled passages supply oil to the main and connecting rod bearings, but oil for the lubrication and cooling of the piston assembly may be supplied by centrifugal force or by separate supply lines. Additional information on variations in engine lubricating systems is given in a subsequent chapter.

CRANKSHAFT THROW ARRANGEMENT.—The smooth operation of an engine and its steady production of power depends, to a great extent, on the arrangement of the cranks on the shaft and on the firing order of the cylinders. In order to obtain uniform rotation of the crankshaft in a multicylinder engine, the power impulses must be equally spaced with respect to the angle of crankshaft rotation and so spaced, when possible, that successive explosions do not occur in adjacent cylinders. (This latter arrangement is not always possible, especially in 2-, 3-, and 4-cylinder engines.)

Crankshafts may be classified according to the number of throws—one-throw, two-throw, etc. The six-throw

shaft illustrated in figure 4–17 is for a six-cylinder, in-line, two-stroke cycle engine. Shafts of similar design could be used in a 12-cylinder, V-type engine and in a 24-cylinder pancake or vertical shaft engine.

The number of cranks and their arrangement on the shaft depend upon a number of factors, such as the arrangement of the cylinders (in-line, V-type, pancake, flat, etc.), the number of cylinders and the operating cycle of the engine. The arrangement of throws with respect to one another and with respect to the circumference of the main journals is generally expressed in degrees. In an in-line engine, the number of degrees between throws indicates the number of degrees the crankshaft must rotate to bring the pistons to TDC in firing order. This is not true in engines where each throw serves more than one cylinder. See figure 4–20 which lists examples of the arrangements of throws with respect to cylinder arrangement, the number of cylinders served by each throw, and the firing order of the cylinders. (The sketches in figure 4–20 are not to scale; therefore, relative size is not indicated. The sketches in this figure are for illustrative purposes only.)

In studying these examples, remember that the crankshaft must make only one revolution (360°) in a two-stroke cycle; whereas two revolutions are required in a four-stroke cycle. In examples (a) and (b), the shafts have the same number of throws, but other factors are somewhat different. Since the four-cylinder engine (example a) operates on the 4-stroke cycle, throws 1 and 3, 3 and 4, 4 and 2, and 2 and 1 (see firing order) must be 180° apart in order for the firing to be spaced evenly in 720° of crankshaft rotation. In the case of the 16-cylinder pancake engine (example b), the situation is somewhat different. Firing must take place within fewer degrees of shaft rotation in order for all cylinders to fire within the cycle. Since 16 cylinders must fire in 360° shaft rotation in a two-stroke cycle engine, there can be only $22\frac{1}{2}$° shaft rotation between firings. To accomplish this,

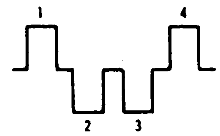
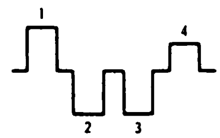
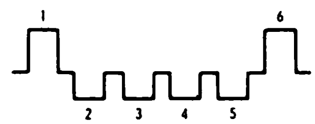
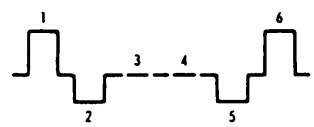
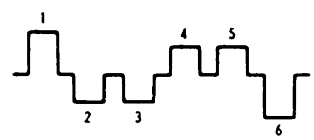
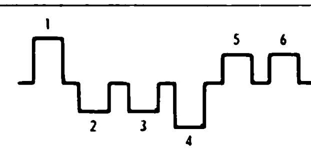
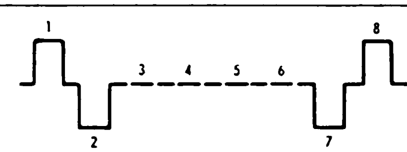
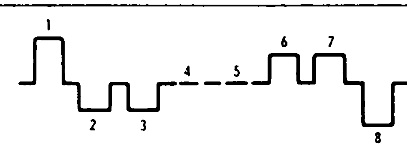
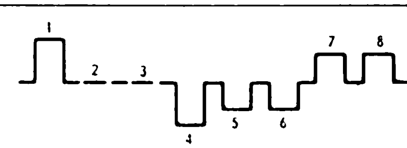
EXAMPLE	NUMBER CYLINDERS	CYLINDER ARRANGEMENT	CYCLE	NO. CYL. SERVED BY EACH THROW	THROW ARRANGEMENT (SIDE VIEW)
(a)	4	IN-LINE	4-STROKE	1	
(b)	16	PANCAKE	2-STROKE	4	
(c)	6	IN-LINE	4-STROKE	1	
(d)	12	V	4-STROKE	2	
(e)	6	IN-LINE	2-STROKE	1	
(f)	12	V	2-STROKE	2	
(g)	8	IN-LINE	4-STROKE	1	
(h)	8	IN-LINE	2-STROKE	1	
(i)	16	V	2-STROKE	2	

Figure 4—20.—Examples of crankshaft throw arrangement.

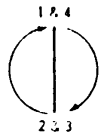
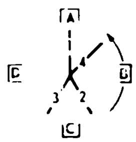
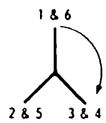
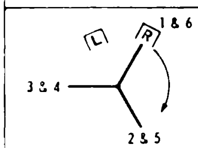
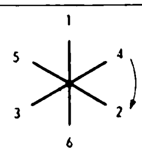
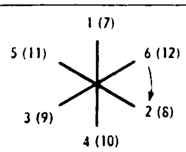
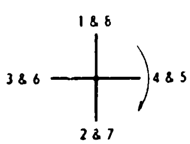
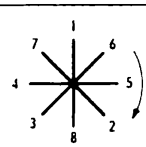
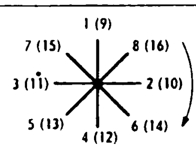
THROW ARRANGEMENT (END VIEW)	FIRING ORDER	NO. DEGREES BETWEEN THROWS (SEE SKETCHES)	NO. DEGREES SHAFT ROTATION BETWEEN FIRINGS
	1-3-4-2	4 THROWS 180° APART	180
	BANK A, CYLINDER 1, C3, A4, B2, D1, B3, D4, A2, C1, A3, C4, D2, B1, D3, B4, C2	4 THROWS UNEVEN NO. DEGREES APART	22½
	1-5-3-6-2-4	6 THROWS 120° APART	120
	L: 1 2 3 4 5 6 R: 1 2 3 4 5 6 1R, 3L, 4R, 5L, 2R, 1L, 6R, 4L, 3R, 2L, 5R, 6L	6 THROWS 120° APART	60
	1-5-3-6-2-4	6 THROWS 60° APART	60
	1 2 3 4 5 6 7 8 9 10 11 12 1-11-5-9-3-10-4-8-2-12-6-7	6 THROWS 60° APART	30
	1-3-2-5-8-6-7-4	8 THROWS 90° APART	90
	1-7-4-3-8-2-5-6	8 THROWS 45° APART	45
	9 10 11 12 13 14 15 16 1 2 3 4 5 6 7 8 1-15-7-11-3-13-5-12-4-14-6-10-2-16-8-9	8 THROWS 45° APART	22½

Figure 4–20.—Continued.

the crankpins are spaced at unequal angles to obtain uniform cylinder firing intervals in the 90° cylinder banks. Shafts with throw arrangements of this type are the exception and not the rule. Note that in all other examples, the throws are equally spaced, regardless of cylinder arrangement, cycle of operation, or number of cylinders.

In examples (c) and (d), the shaft design and the number of degrees between throws are the same. Yet the shaft in example (d) fires twice as many cylinders. This is possible because one throw, through a fork-and-blade rod, serves two cylinders which are positioned in 60° banks. Thus, even though both engines operate on the 4-stroke cycle, the 12-cylinder engine requires only 60° shaft rotation between power impulses.

In examples (e) and (f), you will find other variations in shaft throw arrangement and firing order. You will note that the differences are governed to a great extent by the cylinder arrangement, the number of cylinders served by the shaft and by each throw, and the operating cycle of the engine. How these factors influence throw arrangement and firing order can be seen by comparing some of the examples. For instance, there are six throws shown in example (c) and (e), yet they are 120° apart in one and 60° apart in the other. Why? The cylinder arrangement, the total number of cylinders, and the number of cylinders served by each throw are the same. In the case of examples (c) and (e), the operating cycle is the controlling factor in throw arrangement. This is not true in the case of examples (e) and (f). Both shafts have six throws located 60° apart and the operating cycle is the same in both examples. However, the amount of crankshaft rotation between firings is 30° less in example (f) than in example (e). Then, the controlling factors in these examples are cylinder arrangement, total number of cylinders served, and the number of cylinders served by each throw. (In the end views of examples (f) and (i), in the Throw Arrangement column, figure 4–20, the numbers in parentheses identify the additional cylinders

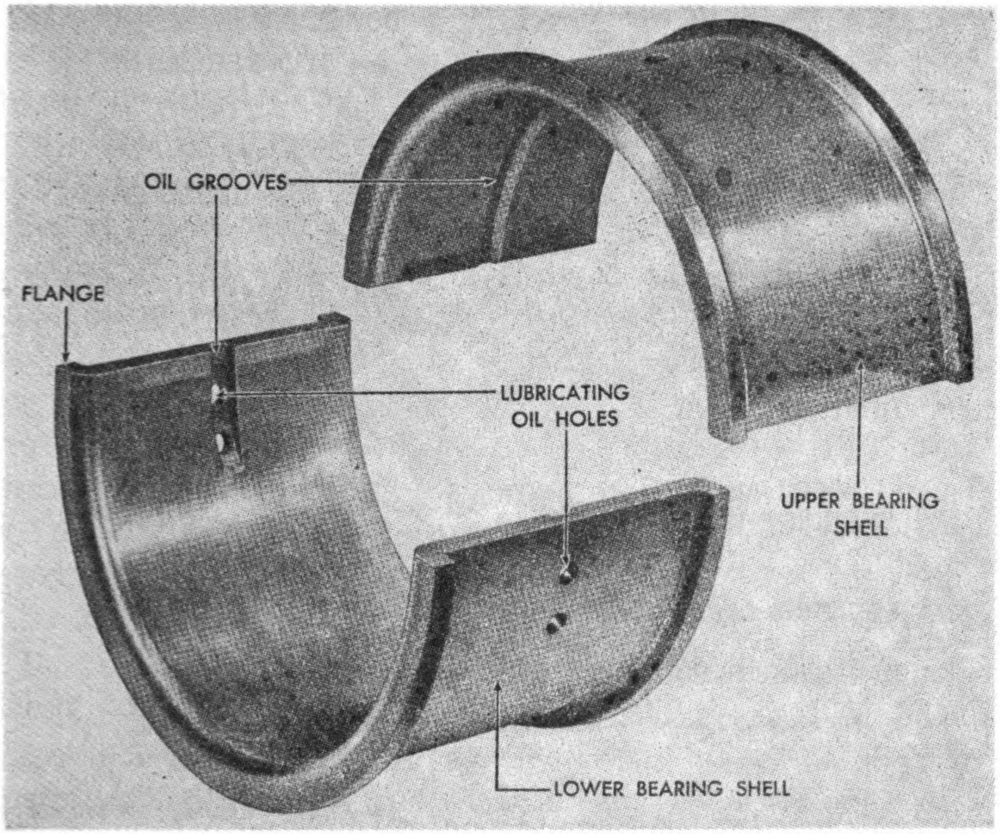


Figure 4–21.—Main journal bearing shells.

served by the throw; for instance, the numbers 1 (7) in example (f) signify that number 1 crankpin serves cylinders 1 and 7.)

Examples (g) through (i) show variations in eight-throw crankshafts.

CRANKSHAFT BEARINGS.—The bearings which act as supports, and in which the main journals of a crankshaft revolve, are generally referred to as MAIN BEARINGS. Main bearings in most engines are of the sliding contact, or plain, type consisting of two halves or shells. (See fig. 4–21.) The locations of main engine bearings in one type of block is shown in figure 4–22.

Main bearings are subjected to a fluctuating load. This is also true of the crankpin bearings and the piston-pin bearings. However, the manner in which main journal

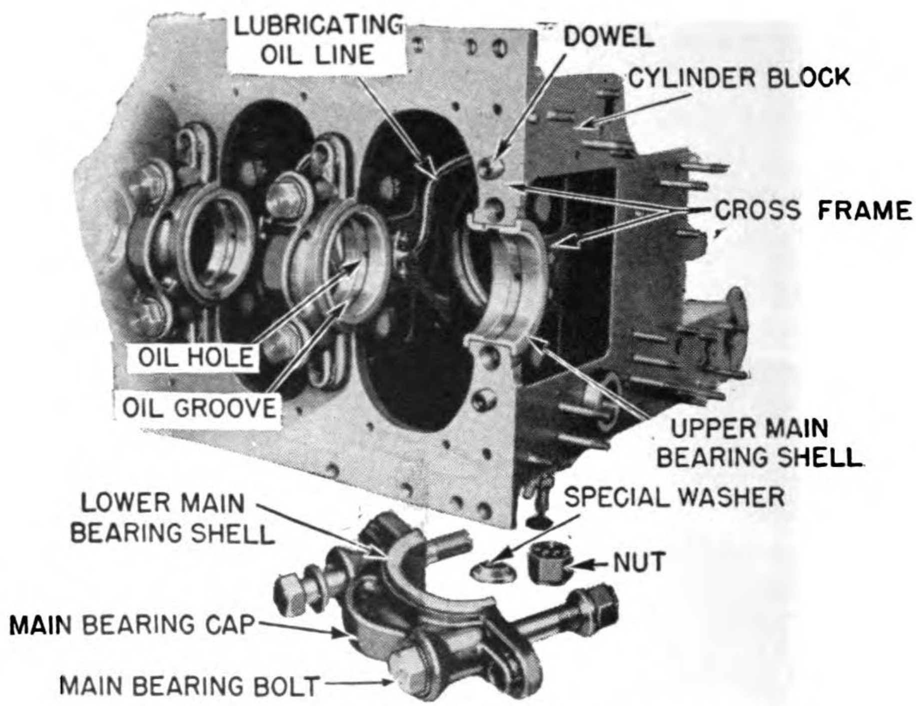


Figure 4–22.—Main bearings in cylinder block (GM268A).

bearings are loaded depends upon the type of engine in which they are used.

In a 2-stroke cycle engine, a load is always placed on the lower half of the main bearings and the lower half of the piston pin bearings in the connecting rod; but upon the upper half of the connecting rod bearings at the crankshaft end of the rod. This is true because the forces of combustion are greater than the inertia forces created by the moving parts.

In a 4-stroke cycle engine, the load is applied first on one bearing shell and then on the other. The reversal of pressure is the result of the large forces of inertia imposed during the intake and exhaust strokes. In other words, inertia tends to lift the crankshaft in its bearings during the intake and exhaust strokes.

There is a definite reversal of load application on the main bearings of a double-acting engine. In this case, the reversal is caused by combustion taking place first on one end of the piston and then on the other.

The main journal bearings of most Navy marine engines may be divided into three principal groups according to the construction of the bearings and the materials used. One group includes the BRONZE-BACK SATCO and STEEL-BACK SATCO BEARINGS. These bearings are sometimes referred to as the bimetal type. This type bearing consists of a bronze or steel back bonded with a bearing material of high lead content. The specifications for the back material are based on the type of bearing and the service for which it is intended. The bearing material, known as Satco, consists of about 98 percent lead and one percent tin.

Another group of bearings is referred to as TRI-METAL bearings. A bearing of this type has a steel back, bonded with an intermediate layer of bronze to which is bonded a layer of bearing material. The bearing material is either lead-base babbitt or tin-base babbitt.

COPPER-LEAD main journal bearings are usually constructed of a layer of copper-lead bonded to a steel back. In other cases, such bearings consist only of a copper-lead shell. Copper-lead bearings are sometimes plated with tin-lead or indium. This plating serves primarily as a protective coating against corrosion. Bearings of the copper-lead type are relatively hard; therefore, when copper-lead bearings are used the journal surfaces of the shaft must be harder than those required when other types of bearings are used. This point should be kept in mind when bearings are being replaced.

Main bearings of the precision type with shims are installed in some large engines. Shims provide a means of adjustment to compensate for wear. The bearings of medium and small engines have no shim adjustment. When nonadjustable bearings have worn the prescribed amount, they must be replaced.

Main bearings and their housing and caps are precision machined with a tolerance sufficiently close that, when properly installed, the bearings are in alignment with the journals and fit with a predetermined clearance. This

clearance provides space for the thin film of lubricating oil which is forced, under pressure, between the journals and the bearing surfaces. Under normal operating conditions, the film of oil surrounds the journals at all engine load pressures. Lubricating oil enters the bearing shells from the engine lubricating system, through oil inlet holes and oil grooves in the bearing shells. (See fig. 4–22.) These inlets and grooves are located in the low pressure area of the bearing.

Additional information on bearings in general, and on the principles of bearing lubrication, is given in NavPers 16178-A, *Fundamentals of Diesel Engines,* chapter 10.

Flywheels

The speed of rotation of the crankshaft increases each time the shaft receives a power impulse from one of the pistons; and it then gradually decreases until another power impulse is received. These fluctuations in speed (their number depending upon the number of cylinders firing in one crankshaft revolution) would result in an undesirable situation, with respect to the driven mechanism as well as the engine; therefore, some means must be provided to stabilize shaft rotation. In some engines, this is accomplished by installing a flywheel on the crankshaft; in others, the motion of such engine parts as the crankpins, webs, lower ends of connecting rods, and such driven units as the clutch, generator, etc., serve the purpose. The need for a flywheel decreases as the number of cylinders firing in one revolution of the crankshaft and the mass of the moving parts attached to the crankshaft increases.

A flywheel stores up energy during the power event and releases it during the remaining events of the operating cycle. In other words: when the speed of the shaft tends to increase, the flywheel absorbs energy, and when the speed tends to decrease, the flywheel gives up energy to the shaft in an effort to keep shaft rotation uniform. In doing this, a flywheel (1) keeps variations in speed within desired limits at all loads; (2) limits the increase or de-

crease in speed during sudden changes of load; (3) aids in forcing the piston through the compression event when an engine is running at low or idling speed; and (4) helps bring the engine up to speed when it is being cranked.

Flywheels are generally made of cast iron, cast steel, or rolled steel. Strength of the material from which the flywheel is made is of prime importance because of the stresses created in the metal of the flywheel when the engine is operating at maximum designed speed.

In some cases, a flywheel is the point of attachment for such items as a starting ring gear, turning ring gear, or an overspeed safety mechanism. The rim of a flywheel may be marked in degrees. With a stationary pointer attached to the engine, the degree markings can be used to determine the position of the crankshaft when the engine is being timed.

OTHER COMPONENTS OF AN ENGINE

This chapter and the preceding chapter have by no means covered all of the parts which make a complete engine. Since many engine components are commonly associated with the SYSTEMS OF AN ENGINE, many of the parts not covered to this point are discussed in connection with the applicable system which they affect. For example, the valves and valve-operating mechanism, which might be considered in the group of main moving parts, are covered in connection with the engine air system. Parts such as blowers, pumps, heat exchangers, etc., sometimes referred to as ENGINE ACCESSORIES or auxiliaries, are discussed in connection with the appropriate engine systems.

The systems commonly associated with the engine proper are those necessary to make combustion possible, and those which minimize and dissipate heat created by combustion and friction. Since combustion requires air, fuel, and heat (ignition), systems providing each may be found on some engines. However, since a Diesel engine generates its own heat for combustion within the cyl-

inders, no separate ignition system is required for engines of this type. The problem of heat, created as a result of combustion and friction, is taken care of by two separate systems—cooling and lubrication. The parts which make up these five systems (air, fuel, ignition, cooling, lubricating), operation of the systems, and some of the maintenance problems common to each system are discussed in the following chapters.

SUMMARY

The process of transmitting the power developed in an engine cylinder to the output shaft involves motion of many engine parts. The main parts are the pistons, connecting rods, and the crankshaft; however, many related parts must be considered in the process of changing reciprocating motion to rotary motion. A piston, which may be of the trunk type or the crosshead type, receives the force of combustion and transmits it to the crankshaft through a connecting rod. The four types of rods most common to Navy marine engines are the conventional, fork-and-blade, padded, and forked.

To accomplish its function, the piston must be fitted with piston rings. In most cases, pistons are fitted with two types of rings—compression and oil. Piston rings function to maintain a gastight seal between the piston and cylinder wall, assist in cooling the piston, and control cylinder-wall lubrication.

Trunk type pistons are fastened to the connecting rods by pins which may be stationary, semifloating, or full-floating. Crosshead pistons are connected to the connecting rods by piston rods and crosshead assemblies. Side thrust created by combustion and the motion of the moving parts is received by the cylinder wall through a trunk type piston, the crosshead assembly absorbs the side thrust in engines fitted with crosshead type pistons.

The crankshaft, one of the largest of the moving parts of the engine, receives the power impulses from all cylinders of the engine, transforms the motion of the

pistons and connecting rods into rotary motion, and transmits the resulting torque to the flywheel or driven unit.

Other important parts which must be considered in connection with main, moving parts of the engine are the bearings. Engine bearings may or may not involve motion, depending on their location and function. Bearings associated with the piston pin may be of the integral, sleeve, or roller types. The sleeve type bearing is the most common and is usually constructed of bronze or similar metal. Bearings associated with the shaft end of connecting rods and the crankshaft are generally of the two-part, precision shell type. Various combinations of metals have been used for rod and shaft bearings. The most common bearings now in use are of the bimetal or trimetal construction and are sometimes referred to as Satco, Trimetal, and Copper-lead bearings.

As in the case of the main stationary parts of the engine, you should be thoroughly familiar with all of the principal moving parts of the engine. You should know the types, construction and materials, functions, and operating principles of these parts; and how these parts are related to the stationary parts. You should be able to associate each component, as discussed separately, with other related components of the engine and know how each part or assembly is related to the cycle of engine operation.

QUIZ

1. With respect to motion, the main moving parts of an engine may be divided into what three major groups?
2. List the comparative advantages of the two metals most commonly used in piston construction.
3. Why is the diameter of the crown end of some pistons slightly smaller than the skirt end?
4. Why are recesses provided in the rims of some concave type piston crowns?
5. Name three types of piston skirts.
6. What is the primary purpose of piston bosses?
7. What three functions must piston rings perform?
8. Of the three functions performed by the rings of a piston, which is common to both oil and compression rings?
9. What other factor, in addition to pressure exerted by the ring itself, aids the firing ring in sealing the combustion space?
10. What is indicated by black areas on the sealing surfaces of a piston ring?
11. How are piston rings arranged in order to minimize gas leakage through the gaps?
12. When oil rings of a piston are identified as control rings and scraping rings, which type is located closest to the compression rings?
13. What is the function of the oil rings which are located nearest to the compression rings?
14. What is sometimes used with an oil ring to increase the pressure of the ring against the cylinder wall?
15. What are the principal forces to which the pin of a trunk type piston is subjected?
16. In a cylinder fitted with a trunk type piston, does side thrust occur on one side only or alternate from side to side?
17. State briefly three ways by which piston pins may be secured in position.
18. Piston-boss piston-pin bearings are generally of what type?
19. What type of piston pin requires bearings in both the piston bosses and the connecting rod?
20. The bearing surface of sleeve type piston-pin bushings is usually made of what metal?
21. Name two types of bearings which may be used in the crankshaft end of a conventional type connecting rod.
22. Which of the two types of connecting rod bearings is most common?
23. What is the principal difference between bearing shells of a conventional rod and a fork-and-blade rod?

24. What type of connecting rod does not have a separate bearing cap at the crankshaft end?
25. How are rods which do not have a separate bearing cap fastened to the crankshaft?
26. The forked type connecting rod is designed for use in connection with what type piston?
27. What is the purpose of a crosshead assembly?
28. Briefly, what is the difference in the direction of side thrust in (a) the cylinder of an engine fitted with a trunk type piston and (b) the cylinder of a double-acting engine?
29. What is the purpose of the gibs which form part of some crosshead assemblies?
30. If the piston of a crosshead piston-and-rod assembly is designed to rotate as the engine operates, what causes the rotation?
31. State two reasons why the pins and journals of some crankshafts are of hollow construction.
32. What may be attached to or constructed as part of a crankshaft to prevent excessive vibration which may result from the rotating action of the shaft?
33. Is the number of degrees between crank throws the same as the number of degrees of crankshaft rotation between firings in an in-line engine? In other types of cylinder arrangements?
34. What is the difference between the ways load is placed on the main bearings of 2-stroke cycle and 4-stroke cycle engines?
35. On the basis of metal and construction, name three types of main journal bearings.
36. What is the primary purpose of the tin-lead plating which is applied to some copper-lead bearings?
37. What must be done to compensate for excessive wear of main journal bearings which have no shim adjustment?

CHAPTER 5

ENGINE AIR SYSTEMS

From past experience, you are well aware that combustion requires air, fuel, and heat. Certain amounts of all three are necessary if an engine is to operate. This chapter deals only with AIR as required to support combustion in the cylinder of an engine. The processes of scavenging and supercharging are considered as well as the group of parts involved in supplying the cylinders of an engine with air and removing the waste gases after combustion and the power event are finished. The engine parts which accomplish these functions are commonly referred to as the INTAKE AND EXHAUST systems. These systems are closely related and, in some cases, are referred to as the air system of an engine. A cross-sectional view of the air systems of one type of high-speed Diesel engine is shown in figure 5–1.

INTAKE SYSTEMS

This section deals with intake systems of Diesel engines only; nevertheless, much of the information dealing with the parts of Diesel engine air systems is also applicable to most of the parts in similar systems of gasoline engines. However, the intake event in the cycle of operation of a gasoline engine includes the admission of air and fuel as a mixture to the cylinder. For this reason, the intake system of a gasoline engine differs, in some respects, from that of a Diesel engine. The engine parts involved in these differences are covered in the training course, *Engineman 2*.

Even though the primary purpose of a Diesel engine intake system is to supply the air required for combustion, the system generally has to perform one or more additional functions. In most cases, the system cleans the air and reduces the noise created by the air as it enters the engine. In order to accomplish the functions of intake, an intake system may include an air silencer, an air

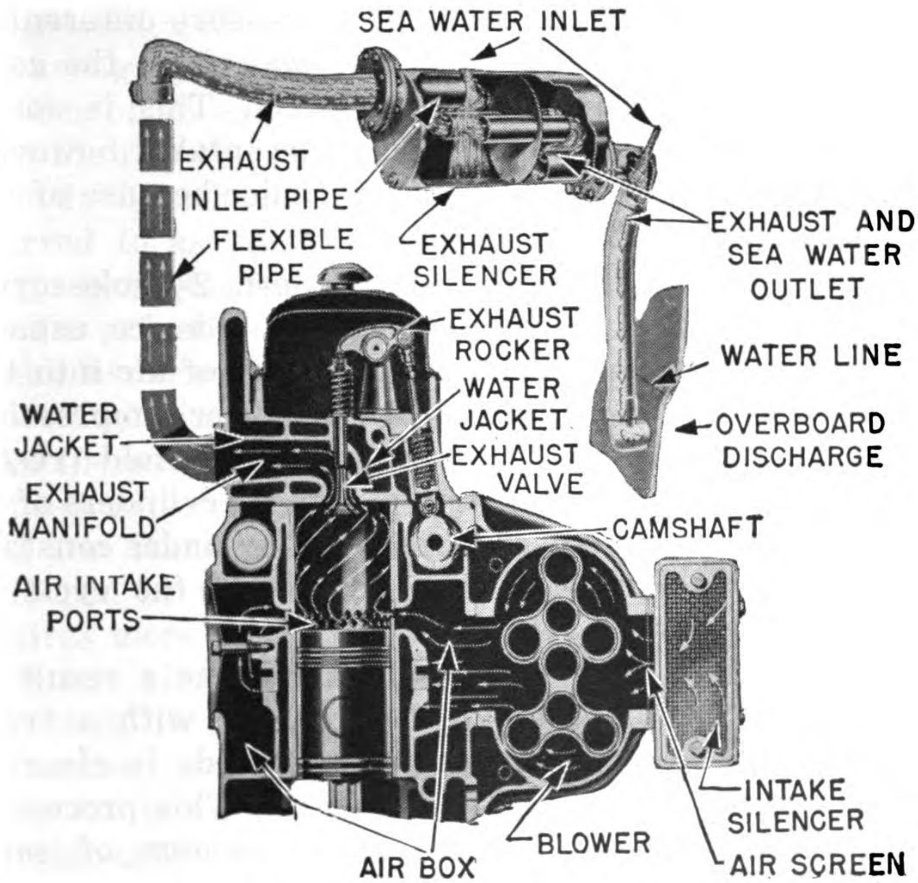


Figure 5–1.—Air systems of a 2-stroke cycle engine (GM71).

cleaner and screen, an air box or header, intake valves or ports, a blower, an air heater, and an air cooler. All of these parts are not common to every intake system. An intake system in which only a silencer, a screen, a blower, an air box, and intake ports provide a clean supply of air, with minimum noise, to the combustion spaces is shown in figure 5–1.

Scavenging and Supercharging

Before considering the parts which may be included in an air-inlet system, you should be thoroughly familiar with the meaning and significance of two terms used frequently when discussing intake systems of Diesel engines. These terms—scavenging and supercharging—and the processes they identify are not common to all Diesel engines. In a few 4-stroke cycle engines, the air enters the cylinder as a result of a pressure differential created by the piston as it moves away from the combustion space during the intake event. This is sometimes referred to as the "suction" type intake; however, the air is actually forced into the cylinder because of the greater pressure outside the cylinder.

In the intake systems of all modern 2-stroke cycle engines and some 4-stroke cycle engines, a device, usually a blower, is installed to increase the flow of air into the cylinders. This is accomplished by the blower compressing the air and forcing it into an air box or manifold (reservoir) which surrounds or is attached to the cylinders of an engine. Thus, an increased amount of air under constant pressure is available as required during the cycle of operation.

The increased amount of air available as a result of blower action is used to fill the cylinder with a fresh charge of air and, during the process, aids in clearing the cylinder of the gases of combustion. This process is called SCAVENGING. Thus, the intake system of some engines, especially those operating on the 2-stroke cycle, is sometimes called the scavenging system. The air forced into the cylinder is called scavenge air and the ports through which it enters are called scavenge ports.

The process of scavenging must be accomplished in a relatively short portion of the operating cycle; however, the duration of the process differs in 2- and 4-stroke cycle engines. In a 2-stroke cycle engine, the process takes place during the later part of the downstroke (expansion) and the early part of the upstroke (com-

pression). In a 4-stroke cycle engine, scavenging takes place when the piston is nearing and passing TDC during the latter part of an upstroke (exhaust) and the early part of a downstroke (intake). The intake and exhaust openings are both open during this interval of time. The overlap of intake and exhaust permits the air from the blower to pass through the cylinder into the exhaust manifold, cleaning out the exhaust gases from the cylinder and, at the same time, cooling the hot engine parts.

Scavenging air must be so directed, when it enters the cylinder of an engine, that the waste gases are removed from the remote parts of the cylinder. The two principal methods by which this is accomplished are sometimes referred to as PORT scavenging and VALVE scavenging. Port scavenging may be of the direct (or cross-flow), loop (or return), or uniflow type. (See fig. 5–2.) The basic principles for each type of scavenging are given in *Fundamentals of Diesel Engines, U. S. Navy,* NavPers 16178A.

An increase in air flow into cylinders of an engine can be used to increase power output, in addition to being used for scavenging. Since the power of an engine is developed by the burning of fuel, an increase of power requires more fuel; the increased fuel, in turn, requires more air, since each pound of fuel requires a certain amount of air for combustion. Supplying more air to the combustion spaces than can be supplied through the action of atmospheric pressure and piston action (in 4-stroke cycle engines) or scavenging air (in 2-stroke cycle engines) is called SUPERCHARGING.

In some 2-stroke cycle Diesel engines, the cylinders are supercharged during the air intake simply by increasing the amount and pressure of scavenge air. The same blower is used for supercharging and scavenging. Whereas scavenging is accomplished by admitting air under low pressure into the cylinder while the exhaust valves or ports are open, supercharging is done with the exhaust ports or valves closed. This latter arrangement enables the blower to force air under pressure into the cylinder and

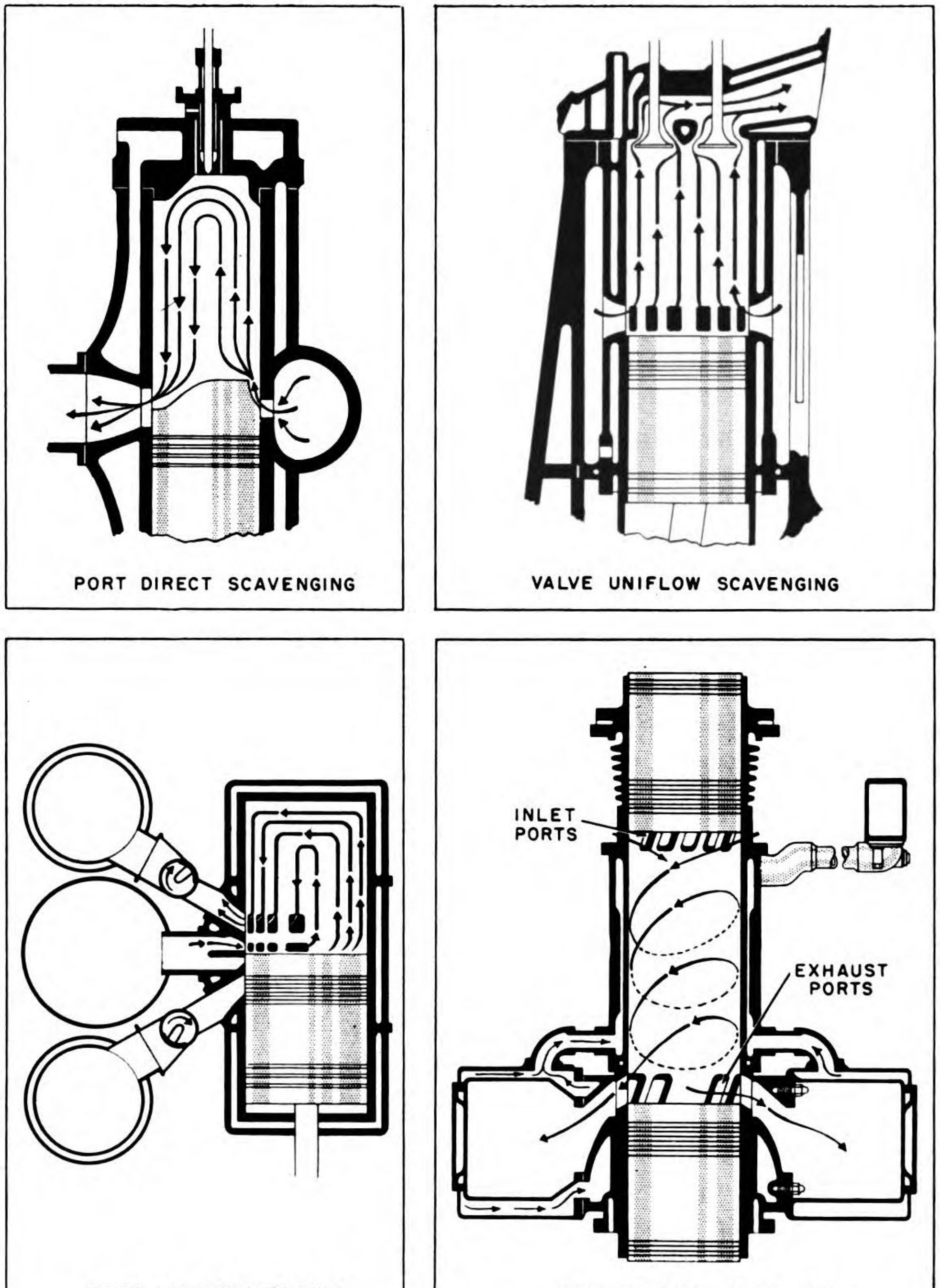


Figure 5—2.—Methods of scavenging—Diesel engines.

thereby increase the amount of air available for combustion. The increase in pressure resulting from the compressing action of the blower will depend upon the engine involved, but it is usually low, ranging from 1 to 5 psi. With this increase in pressure, and the amount of air available for combustion, there is a corresponding increase in the air-fuel ratio and in combustion efficiency within the cylinder. In other words, a given size engine which is supercharged can develop more power than the same size engine which is not supercharged.

Supercharging a 4-stroke Diesel engine requires the addition of a blower to the intake system since the operations of exhaust and intake in an unsupercharged engine are performed by the action of the piston. The timing of the valves in a supercharged 4-stroke cycle engine is also different than that in a similar engine which is not supercharged. In the supercharged engine the intake-valve opening is advanced and the exhaust-valve closing is retarded so that there is considerable overlap of the intake and exhaust events. This overlap increases power, the amount of the increase depending upon the supercharging pressure. The increased overlap of the valve openings in a supercharged 4-stroke cycle engine also permits the air pressure created by the blower to be used in removing gases from the cylinder during the exhaust event. How the opening and the closing of the intake and exhaust valves or ports affect both scavenging and supercharging and the differences in these processes as they occur in supercharged 2- and 4-stroke cycle engines can be seen by studying the diagrams in figure 5–3.

As in the case of the diagrams used in chapter 2, the circular pattern represents crankshaft rotation. Some of the events occurring in the cycles are shown in terms of degrees of shaft rotation. However, the numbers (of degrees) shown on the diagrams in figure 5-3 are for purposes of illustration and comparison only. (When dealing with the timing of a specific engine, check the appropriate instructions.)

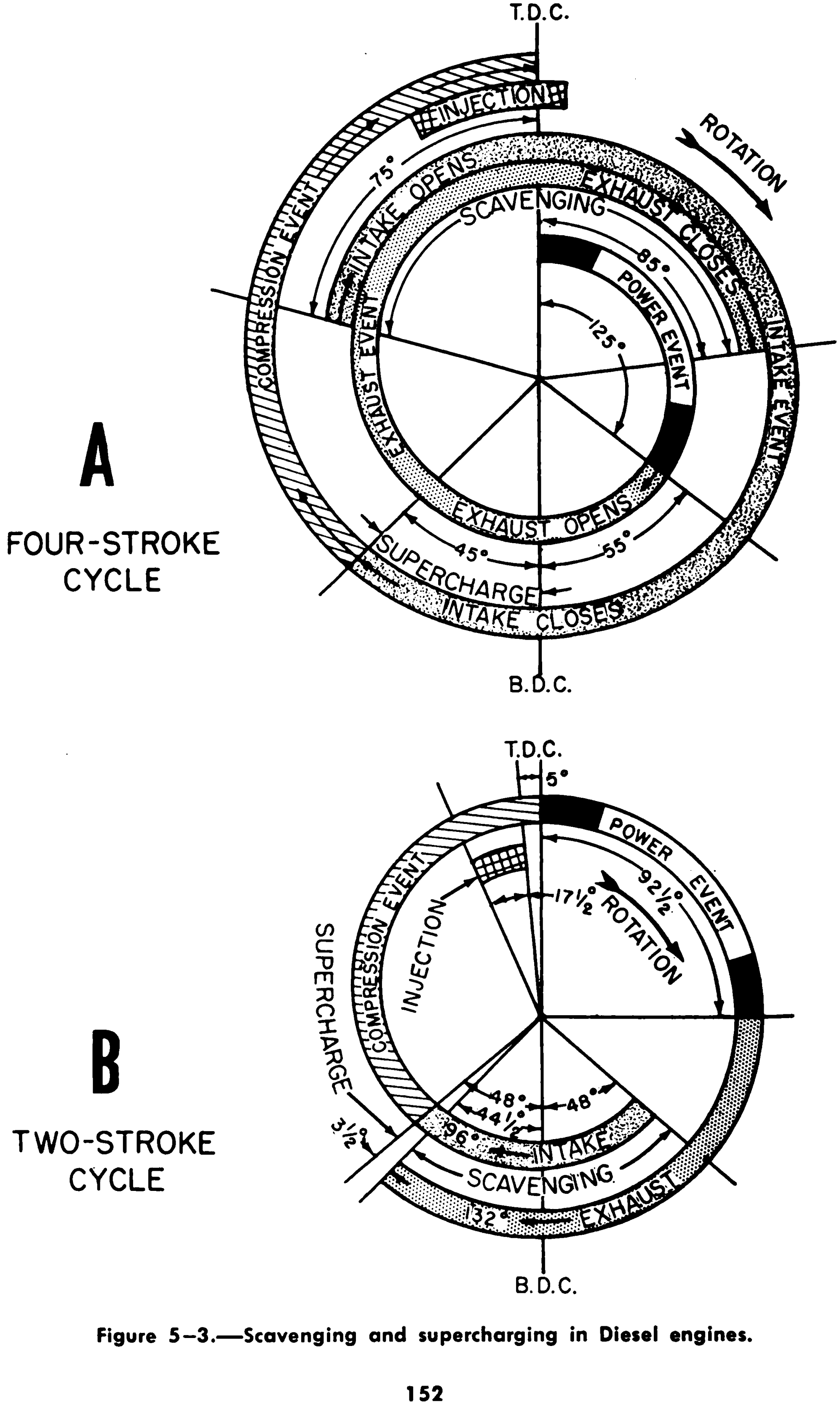


Figure 5–3.—Scavenging and supercharging in Diesel engines.

In studying these diagrams, keep in mind that the crankshaft of a 4-stroke cycle engine makes two complete revolutions in one cycle of operation while the shaft in a 2-stroke cycle engine makes only one revolution per cycle. Also keep in mind that the exhaust and intake events in a 2-stroke cycle engine do not involve complete piston strokes as they do in a 4-stroke cycle engine.

FOUR-STROKE CYCLE SCAVENGING AND SUPERCHARGING. Diagram A of figure 5–3 is based on the operating cycle of the Cooper-Bessemer GSB-8 engine. This engine operates on the 4-stroke cycle and utilizes a centrifugal type blower (turbocharger) to suppy the cylinders with air under pressure.

In a supercharged 4-stroke cycle engine, the duration of each event differs somewhat from the length of the comparable events in a 4-stroke cycle engine which is not supercharged. The intake and exhaust valves are open much longer in a supercharged engine, and the compression and power events are shorter. This arrangement permits a longer period for scavenging. When the exhaust event is completed, the turbocharger fills the cylinder with fresh air under pressure before the compression event begins; in other words, the turbocharger supercharges the cylinders.

The relationship of scavenging and supercharging to the events of the cycle can be more readily understood by referring to the diagram and following through the complete cycle.

Start your study of the cycle at TDC, the beginning of the power event. At this point, peak compression has been reached, fuel injection is nearly completed, and combustion is in progress. Power is delivered during the downstroke of the piston for 125° of crankshaft rotation. At this point in the downstroke (55° before BDC) the power event ends and the exhaust valves open.

The exhaust valves remain open throughout the rest of the downstroke (55°), throughout all of the next up-

stroke (180°), and throughout 85° of the next downstroke, a total of 320° of shaft rotation. At a point 75° before the piston reaches TDC the intake valves open and the turbocharger begins forcing fresh air into the cylinder. For 160° of shaft rotation, the air passes through the cylinder and out the exhaust valves, clearing the waste gases from the cylinder. The rapid flow of gases escaping through the exhaust manifold is utilized to drive the turbocharger. The process of SCAVENGING continues until the exhaust valves close at 85° past TDC.

The intake valves remain open, after the exhaust valves close, for an additional 140° of shaft rotation (45° past BDC). From the time the exhaust valves close until the piston reaches approximately BDC, the cylinder is being filled with air, made available by the blower. During this interval, the increase in pressure is negligible because of the increasing volume of the cylinder space (the piston is in downstroke). However, when the piston reaches BDC and starts the upstroke, the volume of the space begins to decrease as the blower continues to force air into the cylinder. The result is a supercharging effect with the pressure reaching 3 to 5 psi by the time the intake valves close.

During the remainder of the upstroke (after the intake valves close) the supercharged air is compressed. Fuel injection begins several degrees before TDC and ends shortly after TDC. The actual length of the injection period in a specific engine depends on engine speed and load. When the piston reaches TDC, a cycle, involving two complete crankshaft revolutions and four strokes of the piston, has taken place; and the engine is ready to repeat the cycle.

TWO-STROKE CYCLE SCAVENGING AND SUPERCHARGING. By comparing diagrams A and B of figure 5–3, you will note that the length of the supercharging and scavenging periods in a 2-stroke cycle engine is not at all the same as in a 4-stroke cycle engine. Also, you will find considerable difference with respect to piston location be-

tween the times when these processes take place in the two types of engines. In a 4-stroke cycle, scavenging takes place while the piston is traveling through the latter part of the upstroke and the early part of the downstroke; and supercharging takes place when the piston is in the vicinity of BDC. In a 2-stroke cycle, we find that the processes of scavenging and supercharging both take place while the piston is in the lower part of the cylinder. A piston in a 4-stroke cycle engine does much of the work of intake and exhaust, but in a 2-stroke cycle engine the piston does very little work in these two processes. Because of this, many 2-stroke cycle engines are equipped with a blower to force air into the cylinder and to clear out the exhaust gases.

Diagram B of figure 5–3 is based on the operating cycle of the engine shown in figure 5–1. If you follow the diagram and compare it with diagram A, the differences in the scavenging and supercharging processes in 2- and 4-stroke cycle engines should be more apparent.

Start your study of the cycle with the piston at TDC. Fuel has been injected, ignition has occurred, and combustion is taking place. The power developed forces the piston through the power event until the piston is 92½° (125° with the preceding example) past TDC, just a little more than half way through the downstroke. At this point, the exhaust valves open, gases escape through the manifold, and cylinder pressure drops rapidly.

When the piston reaches a point 48° before BDC, the intake ports are uncovered by the piston as it moves downward and scavenging begins. (Compare this with the opening of the intake valves in a 4-stroke cycle.) The scavenging air, under blower pressure, swirls upward through the cylinder and clears the cylinder of exhaust gases. The situation in the cylinder when scavenging starts is approximately the same as that illustrated in figure 5–1 and in figure 5–2, valve uniflow scavenging. Note the position of the piston, the open scavenge ports, the open exhaust valves, and the flow of air through the

cylinder. The flow of scavenge air through the cylinder aids in cooling the parts which are heated by combustion.

Scavenging continues until the piston is 44½° past BDC, (a total of 92½° as compared with 160° in the 4-stroke cycle) at which point the exhaust valves close. In this case, the exhaust valves remain open during only 132°, as compared with the 320° in the example of the 4-stroke cycle. The scavenge ports remain open for another 3½° of shaft rotation (45° in the 4-stroke cycle) and the blower continues to force air into the cylinder. Even though the ports are open for only a short interval of time after the exhaust valves close, sufficient time is available in this interval for the blower to create a supercharging effect before the compression event starts.

The piston closes the intake ports at 48° past BDC. The compression event takes place during the remainder of the upstroke with injection and ignition occurring near TDC. At this point one cycle is ended and another is ready to start.

Intake System Components

There are many variations in the design of the engine parts which function, as a group, to conduct clean air to intake valves or ports, under proper conditions. Regardless of design differences, the purpose of each kind of part remains the same. It is beyond the scope of this course to cover every type of model of each part of engine air-intake systems; therefore, only a few of the common types of each of the principal parts of these systems are discussed here.

SILENCERS, SCREENS, AND CLEANERS.—Since the air that enters the intake system must do so relatively quietly and be as clean as possible, consideration is given first to those parts which accomplish the cleansing and silencing action. A Diesel engine uses a great quantity of air, and, unless a SILENCER is installed, the rush of air through the air-cleaning device will create an extremely high-pitched whistle. Devices used to reduce the noise

of intake air are generally constructed as part of air-cleaning components.

One type of air-intake silencer assembly is shown in figure 5–4. This type of silencer is used on some models of Gray Marine and GM71 engines.

The silencer assembly is bolted to the intake side of the blower. (See fig. 5–1.) A perforated steel partition divides the silencer, lengthwise, into two sections. Air enters the end of the silencer and passes through the inner section, into the blower. The noise created by the air as it passes through the silencer is reduced by a sound-absorbent, flameproof, felted cotton waste which fills the outer section of the silencer.

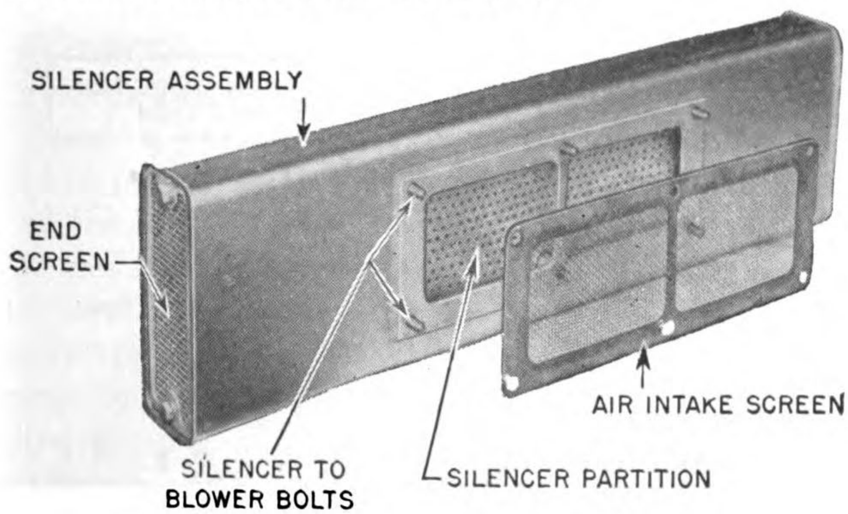


Figure 5–4.—Air-intake silencer assembly (GM71).

Upon leaving the silencer, the air enters the blower through an air-intake SCREEN. (See figs. 5–1, 5–4, and 5–14.) The purpose of the air-intake screen is to prevent particles of foreign material from entering the engine. Unless filtered out of the intake air, foreign material might seriously damage the blower assembly and internal engine parts such as pistons, piston rings, and liners.

The silencer-and-screen assembly just described is sometimes referred to as a DRY type cleaner and silencer. Another type of air cleaner and silencer is the VISCOUS

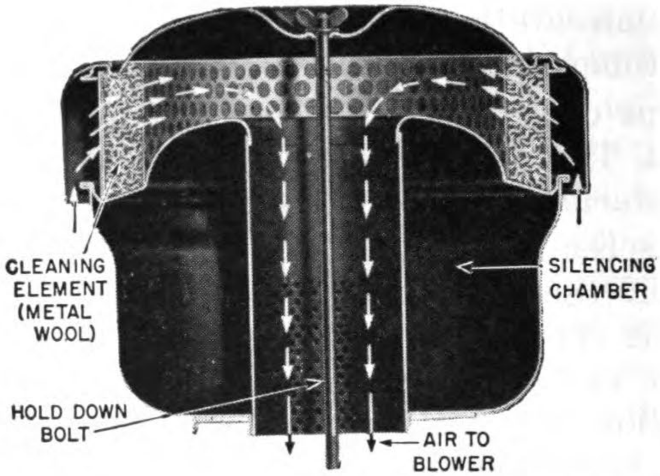


Figure 5–5.—Viscous type air silencer and cleaner (GM71).

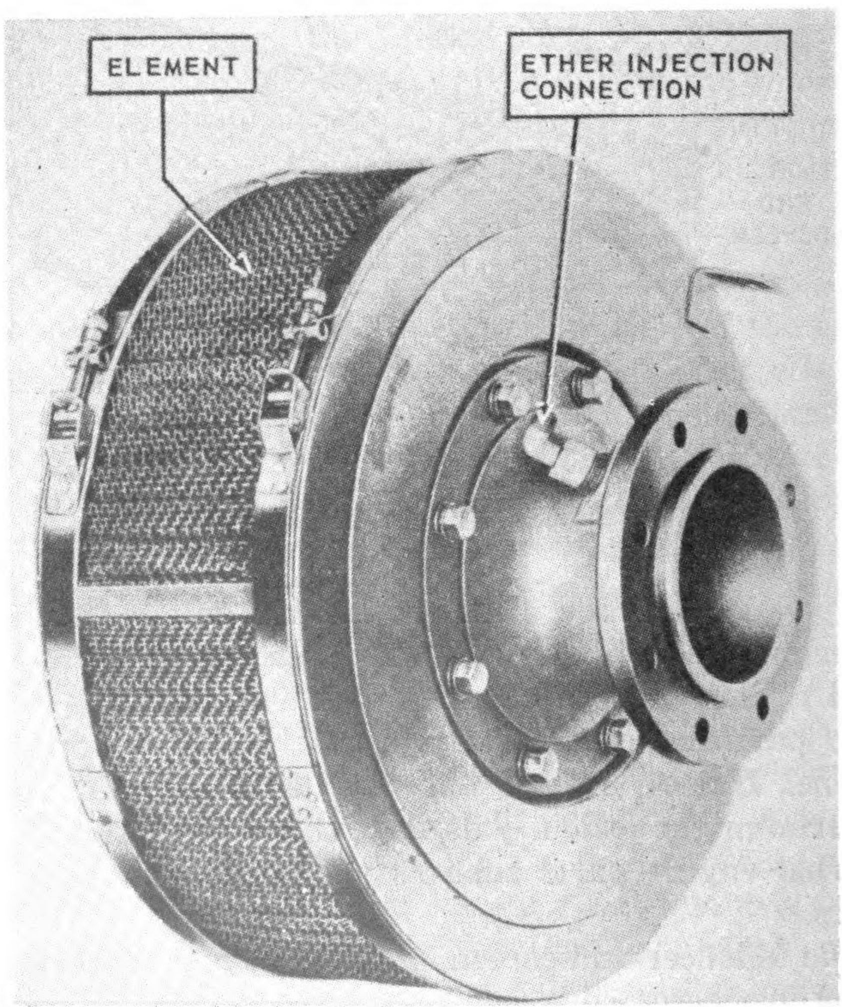


Figure 5–6.—Air filter and silencer (Packard, series 142).

type. In both dry and viscous types intake air is drawn through a fine mesh or screen which filters the air. The mesh of such cleaners may consist of cotton fabric, wire screens, specially wound copper crimp, or metal wool. The principal difference between cleaners of the dry and viscous types is that the mesh of the viscous type cleaner is wet usually, with a medium weight oil. An air cleaner and silencer assembly of the viscous type is shown in figure 5–5. The cleaning element (metal wool, in this case) is oil-soaked to collect the dust and dirt from the air passing through the assembly. The hollow housing which supports this element also serves as a silencing chamber. Assemblies of the type shown are used on some models of Gray Marine and GM71 engines.

The assembly shown in figure 5–6 is another viscous type cleaner and silencer. The filter and silencer of this unit form a cylinder silencing chamber, the ends of which are packed with sound-deadening material. The air inlet of the silencer is located in the circumferential surface of the silencing chamber. The filter element fits over the air inlet. The element of the filter consists of a series of oil-wetted wire baffles which collect any airborne dirt entering the cleaner. Filters of this type are used on Packard Diesels, series 142.

Another type of intake-air cleaner and silencer includes an oil bath as part of the assembly. The cross-section of an OIL BATH air cleaner is shown in figure 5–7.

In oil-bath cleaners, the intake air strikes the oil before passing through the mesh. The inertia of the air-borne dust particles causes some of them to strike and adhere to the oil surface. The mesh collects particles which are not removed by the oil.

Note the similarity of the oil-bath filter in figure 5–7 to the viscous-type cleaner shown in figure 5–5. The principal difference is the oil reservoir in the oil-bath cleaner, which traps the major portion of the dirt entering the system.

The silencer-and-cleaner assemblies described in the

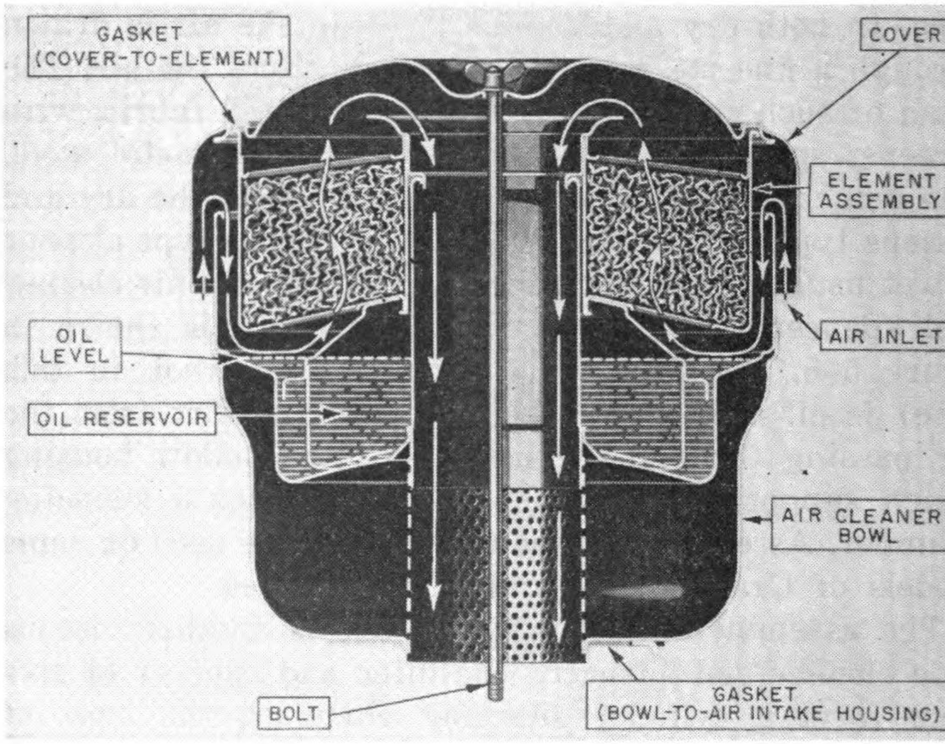


Figure 5–7.—Oil bath air cleaner and silencer assembly (GM71).

preceding paragraphs are representative of the devices used to clean intake air and to reduce the noise it makes as it enters the engine. Regardless of type, air filters should be cleaned as specified by maintenance instructions, to ensure efficient cleaning of the intake air. There are certain precautions that should be observed in using each type of air cleaner. Some of these precautions are given in a subsequent chapter dealing with engine maintenance.

BLOWERS.—As pointed out earlier, blowers are necessary on most 2-stroke cycle engines, to force scavenging air through the cylinders. In addition, a supercharged engine, of either the 2- or 4-stroke cycle type, must have a blower to fill the cylinder with fresh air at a pressure above atmospheric pressure before the compression event starts. Basically, the primary function of an engine blower is to deliver a large volume of air at a low pressure (1 to 5 psi).

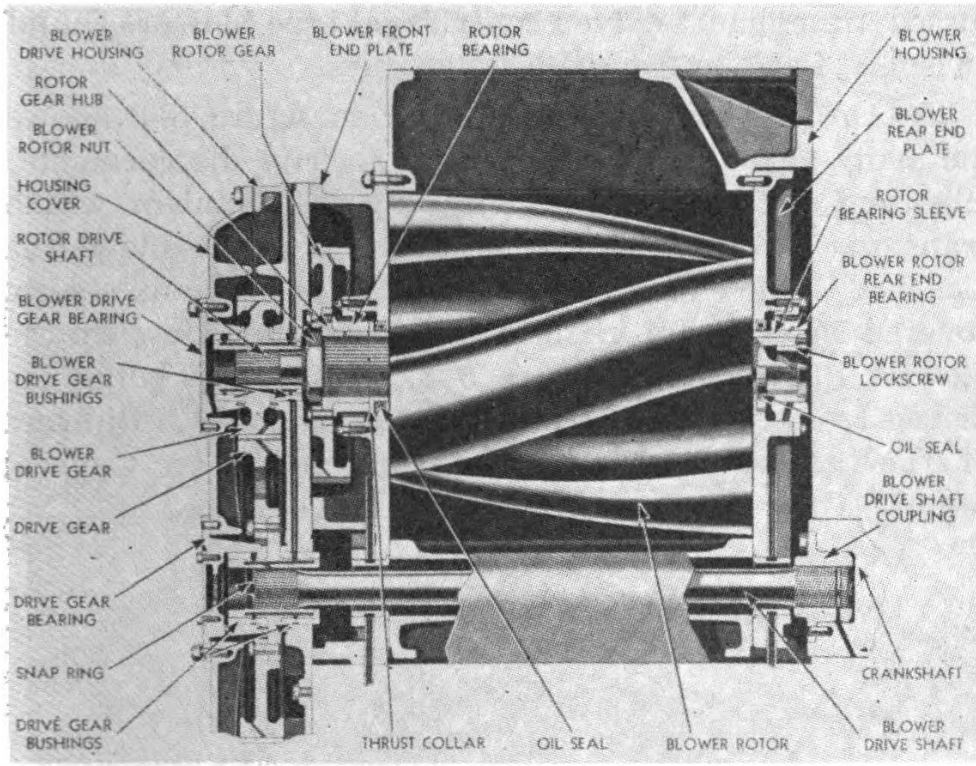


Figure 5–8.—Cross section of a positive displacement blower (GM12 and 16-278A).

There are two principal types of blowers: POSITIVE DISPLACEMENT and CENTRIFUGAL. A positive displacement blower is usually gear driven directly by the engine, while a centrifugal blower is generally driven by an exhaust-gas turbine. Positive displacement blowers may be divided into two groups: the multiple-lobe type, commonly called the LOBE, or Roots, blower; and the AXIAL-FLOW, or Whitfield, blower.

Blowers were introduced briefly in *Fireman*, NavPers 10520-A. A cutaway view, illustrating the principle of operation of the positive displacement blower, was shown. Additional information is given here on blowers of this type and centrifugal blowers are discussed. Since there are many variations in blower design, only examples of the more common designs are discussed in this chapter. The first example, a lobe blower, is commonly used on many 2-stroke cycle engines. The other examples dis-

cussed are exhaust-driven centrifugal type blowers found on some 4-stroke cycle Diesel engines.

The cross section of the blower in figure 5–8 shows the many parts of one design of a positive displacement, lobe-type, rotary blower. The drive mechanism which transmits power from the crankshaft to the blower is attached to the end of the blower. (Drive mechanisms are covered in the next chapter.) An external view of the blower, illustrated in figure 5–8, with rotors being removed from the housing, is shown in figure 5–9. Blowers of this general type are commonly found on General Motors, Gray Marine, and many other engines.

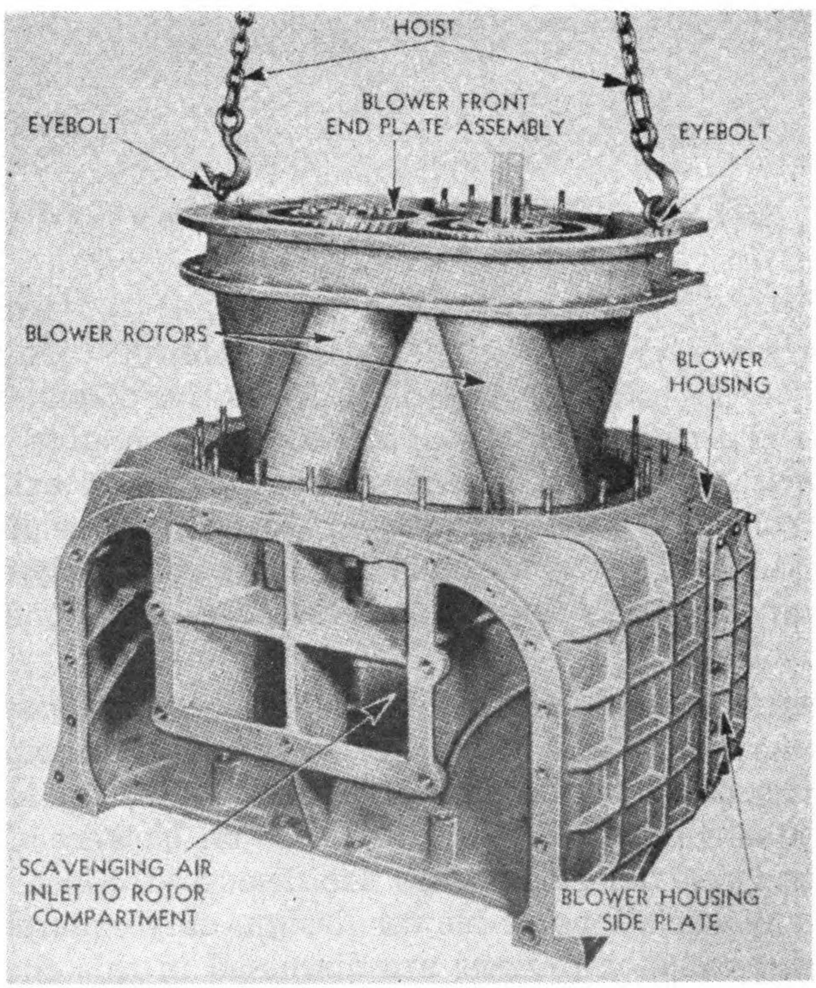


Figure 5–9.—Positive displacement blower—rotors and housing (GM12 and 16-278A).

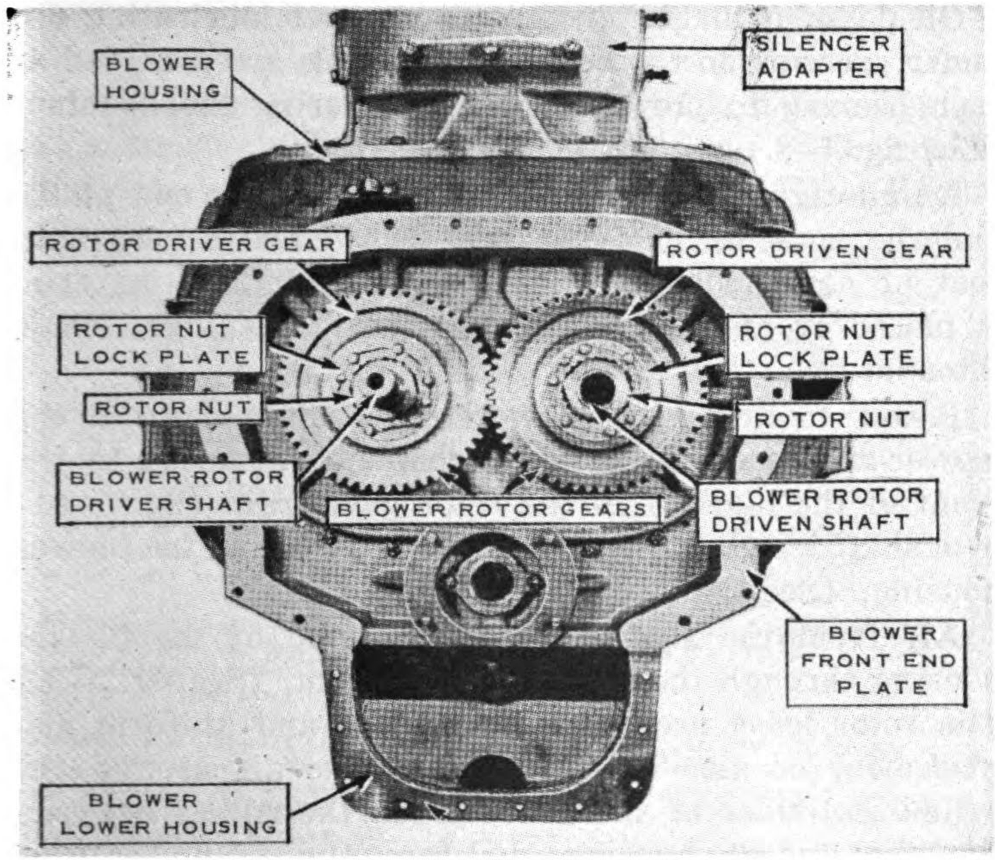


Figure 5–10.—Blower rotor gear train (GM12 and 16–278A).

The blower illustrated has two, three-lobe rotors which rotate in opposite directions within the closely fitted, inner wall of the housing. The rotors do not touch each other or the housing wall which surrounds them. The rotors are mounted on tubular, serrated shafts to which the helical rotor gears are attached. (See fig. 5–10.)

The closely-fitted rotor gears are rigidly attached to the shafts and are timed to prevent the meshing lobes of the rotors from touching. The radial position of each rotor and the clearance between the rotor lobes and the housing are maintained by babbitted bearings located in the blower end plates. The rotor bearings at the gear end have thrust surfaces which maintain the correct axial position of the rotors and prevent contact between the rotors and the end plates. (See fig. 5–8.)

Oil passages in the end plates conduct lubricating oil, under pressure to the bearings. Oil seals are provided at each bearing to prevent oil from entering the housing. (See fig. 5–8.)

An air-tight seal is maintained between the end plates and the housing by a fine silk thread and a very thin coat of non-hardening gasket compound. This material is placed around the housing end-plate openings, inside the stud line. (See line of studs in fig. 5–9.)

Power to drive the blower is transmitted from the blower-and-accessory drive mechanism (attached to the front of the blower) to the rotor gear train (fig. 5–10) by a shaft which extends through a passage in the blower housing. (See fig. 5–8.)

Air from the silencer enters the top of the blower housing through the scavenging air inlet. (See fig. 5–9.) The rotor lobes produce a continuous and uniform displacement of air. The lobes carry the air around the cylindrical sides of the housing (in the spaces between the lobes and the housing) and force the air, under pressure, to the bottom of the housing. An opening in the inner wall of the housing permits the air to pass into the space between the inner and outer walls of the housing, and then out the discharge opening.

Unlike positive displacement blowers, which are driven through a gear train by the engine crankshaft, the centrifugal-type blower, or turbocharger, takes its power from the exhaust gases and thereby makes use of some of the energy which would otherwise be wasted. In brief, the principle of operation of a turbocharger is as follows: (1) the gases from the exhaust manifold drive a gas turbine; and (2) this turbine drives a centrifugal, fresh-air blower, or impeller, which supplies air to the cylinders for scavenging and supercharging. The several types of centrifugal blowers in naval service all operate on this basic principle.

Three of the turbochargers installed on marine engines used by the Navy are the Alco-Buchi, the Elliot-Buchi,

and the General Electric. Even though all of these blowers operate on the same principle and are somewhat similar in external appearance, there are notable differences in the construction of the various types. Some of the main differences between the Alco-Buchi and the Elliot-Buchi turbochargers are given in figure 5–11.

Alco-Buchi	Elliott-Buchi
Lubricated by oil from the engine lubricating system.	Independently lubricated by oil from a separate turbocharger oil tank. The oil pump is usually driven by the turbocharger.
Impeller and turbine are located on the shaft, between the two shaft bearings.	Both shaft bearings are located on the same side of the overhung turbine wheel.
Labyrinth ring seals are located between the shaft and the casing, and between the impeller and the casing.	Labyrinth ring seal is located between the impeller and the casing.
Machined, shaft bearing end-faces serve as thrust bearings. Steel thrust collar and washer, on the turbine end of the shaft, limit longitudinal movement of the shaft.	Steel thrust-collar keyed to the shaft, and working between the machined end-face on the outer shaft bearing and the thrust-bearing face, limits longitudinal movement of the shaft.
Blower case is split horizontally.	Blower case is divided vertically, perpendicular to the center lines of the shaft.

Figure 5—11.—Construction differences in turbochargers.

Figure 5–12 shows a phantom view of the Alco-Buchi turbocharger and figure 5–13 shows two views of the Elliot-Buchi turbocharger. Figure 5–14 shows an external view of the General Electric turbocharger.

Two of the turbochargers mentioned, the Elliot-Buchi and the General Electric, will be described in some detail, as examples of the devices used to supercharge 4-stroke cycle engines. Turbochargers of the Elliot-Buchi type are used on Cooper-Bessemer GSB-8 engines; and Packard Diesels, series 142, are equipped with General Electric turbochargers.

Many of the parts of an Elliot-Buchi turbocharger are

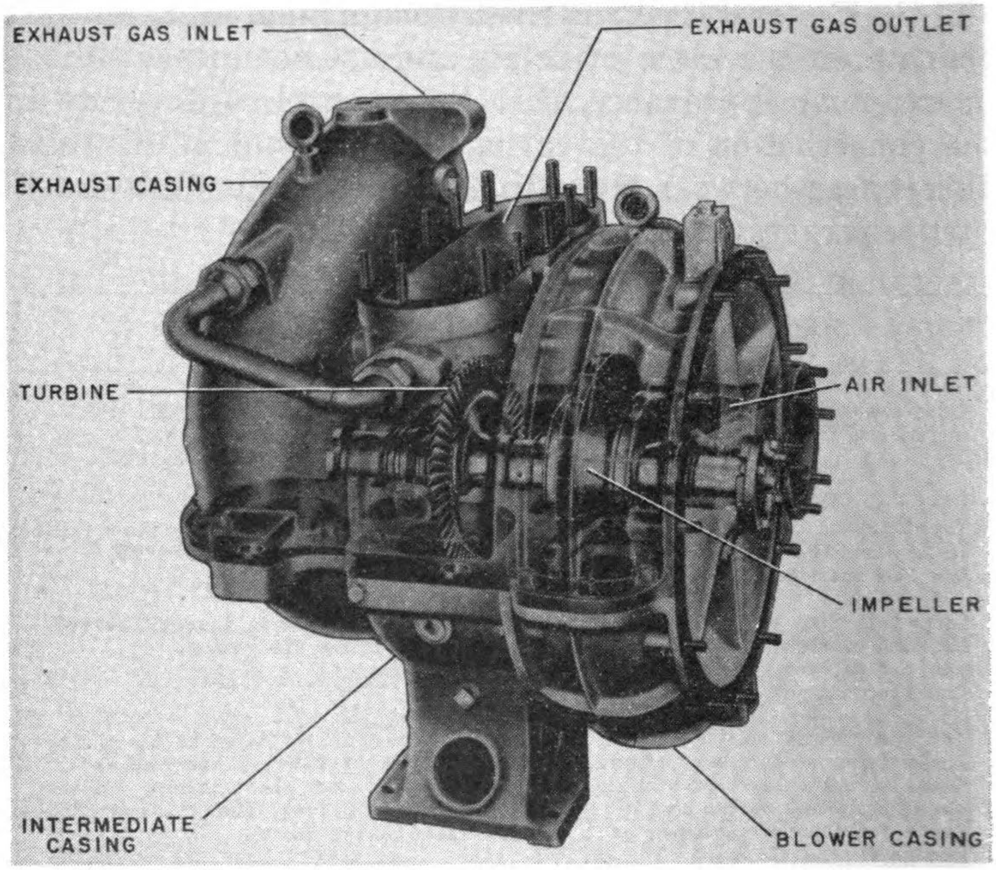


Figure 5–12.—Alco-Buchi turbocharger.

identified in figures 5–13 and 5–14. Different views of some of the parts can be seen by checking both figures. Frequent reference to figures 5–13 and 5–14, as you study the following description, will aid you in becoming familiar with the turbocharger and its operation.

In our discussion we will consider this turbocharger as being divided into four systems: exhaust, intake, cooling, and lubricating. Similar systems are common to other exhaust-driven turbochargers.

The EXHAUST SYSTEM consists of an impulse turbine inside a turbine casing. The system furnishes the driving power for the turbocharger. Gases from the exhaust manifold enter the turbine casing through four inlets. The high-temperature and high-velocity exhaust gases strike the turbine disk and cause it to rotate at high

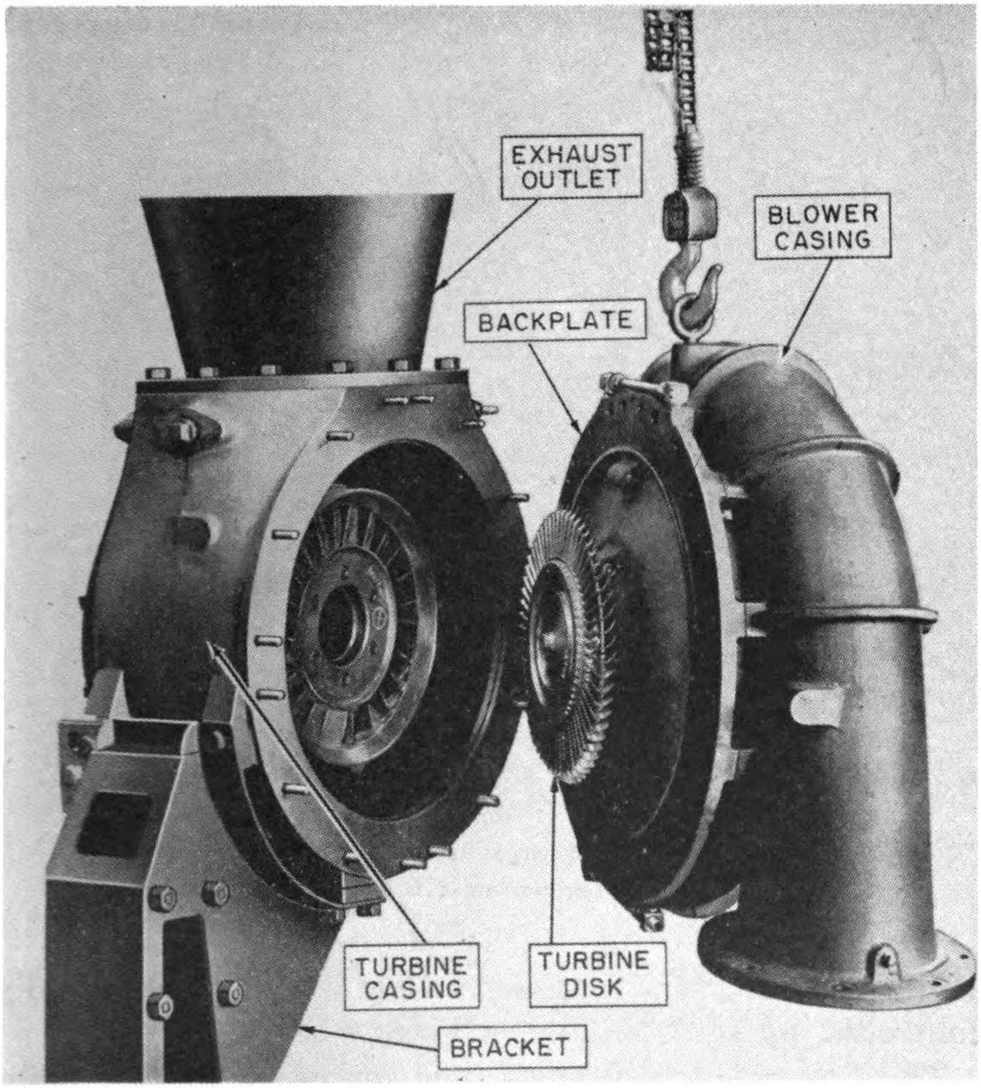


Figure 5–13.—Blower casing assembly removed from turbine casing (Cooper-Bessemer GSB-8).

speed. The direction of rotation of the turbine disk is the same for both directions of engine rotation. The speed of the turbine is automatically controlled by the speed and load of the engine. When the gases have turned the turbine, they are discharged through the exhaust outlet.

The AIR-INTAKE SYSTEM consists of a centrifugal blower mounted in a casing and an air silencer and screen. Since they are mounted on the same shaft, the blower and the turbine disk both rotate at the same speed. This means that in addition to turbine speed, the amount of fresh

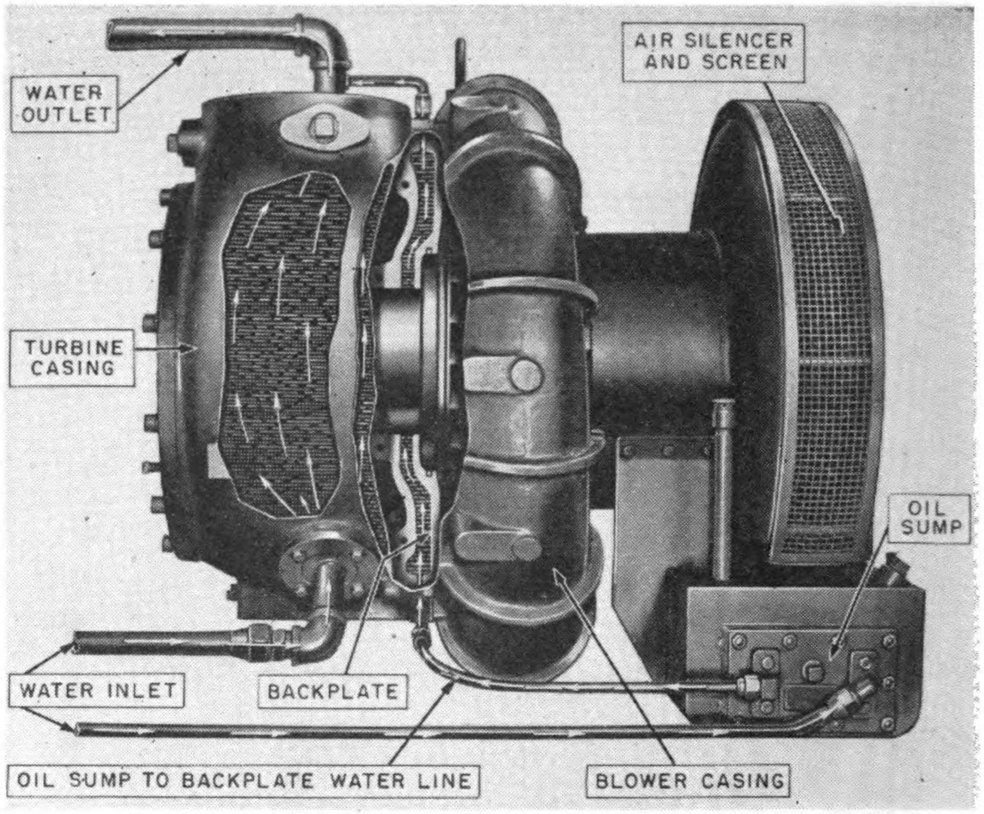


Figure 5–14.—Cooling water system of the turbocharger (Cooper Bessemer GSB-8).

air discharged to the intake manifold is also automatically controlled by the engine speed and load.

The COOLING-WATER SYSTEM is connected to the fresh-water cooling system of the engine. Water circulates through jackets around the turbine casing, the oil sump, and the back plate. The water cools the turbine casing, which is in constant contact with the hot exhaust gases. It also cools the lubricating oil and the back plate, and prevents heat conduction to the fresh-air side of the turbocharger. This is important, because the temperature of the intake air must be kept down since this air aids in cooling the cylinder and the exhaust valves during scavenging.

The LUBRICATING SYSTEM may, or may not, be completely separate from the engine lubricating system. In the separate system, an oil pump is driven, through re-

duction gears, by the shaft of the turbocharger. The pump draws oil from the sump tank and discharges it, through a filter, into the bearing support of the rotating assembly. The pump supplies oil, at the proper pressure, to all the moving parts of the turbocharger. Oil pressure varies with turbocharger speed.

The General Electric turbocharger (fig. 5–15) operates on the same basic principle as the turbocharger just described; however, the GE turbocharger differs from the Elliot-Buchi turbocharger in certain features of design and construction. For example, the GE air filter and cleaner is not an integral part of the blower. The viscous-type assembly shown in figure 5–6 is used in the intake systems of Packard Diesel engines equipped with the GE turbochargers. Even though the GE and Elliot-Buchi turbochargers differ, the following discussion re-

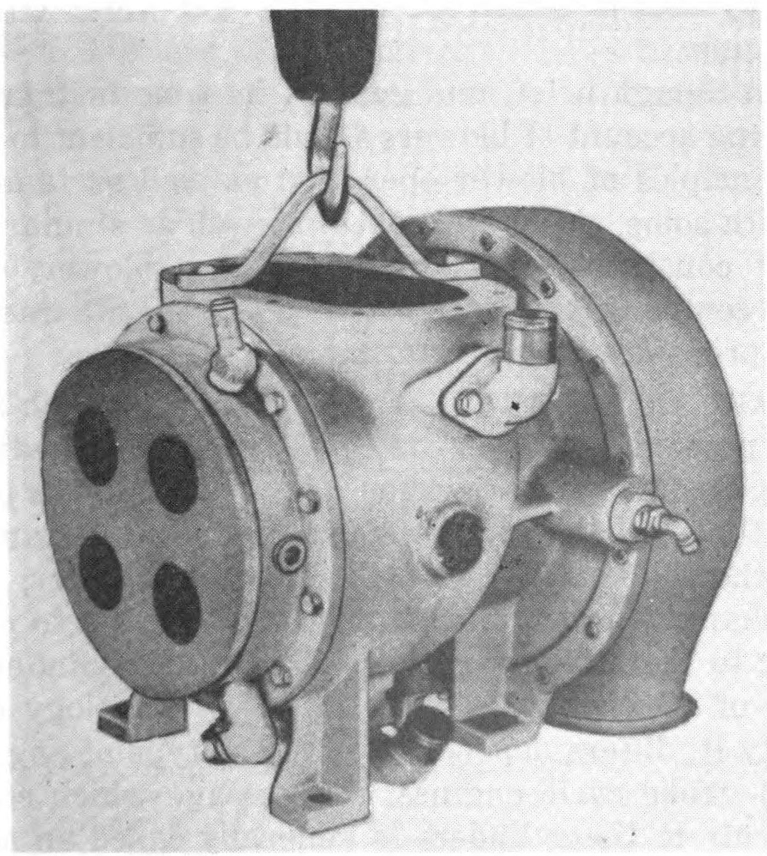


Figure 5–15.—General Electric turbocharger.

veals a number of ways in which the two are similar.

In brief, the GE supercharger consists of an exhaust-gas driven turbine and a centrifugal compressor. The compressor impeller and the turbine wheel are mounted on a common shaft, thus forming a single unit. The compressor consists of an impeller, diffuser, and a casing. All of these parts are usually made of cast aluminum. In later models, the impeller is sometimes made of forged, milled alloy. A water-cooled cast aluminum housing which contains the two journal bearings and the thrust bearing also serves as the turbine exhaust casing. The turbine assembly includes the water-cooled nozzle box, the nozzle ring or diaphragm assembly, and the turbine wheel. All of these turbine parts are made of corrosion-resistant, high-temperature alloys.

Oil for supercharger lubrication is taken from the engine lubricating system. The supercharger cooling water system is connected to the fresh water circuit of the engine.

Even though brief, and general in some instances, the preceding account of blowers should be sufficient to clarify the principles of blower operation as well as familiarize you with some of the differences as well as similarities in blower construction. The details on a blower, or any engine component for that matter should be obtained from the appropriate instruction manual.

INTAKE AIR PASSAGES.—Air must pass through a number of passages to reach the combustion spaces within an engine. So far, this discussion has considered the passage of air through components which clean, silence, and compress the intake air. From the blower, however, the air is discharged into a unit or passage designed to conduct the air to the intake valves or ports of the cylinders. The design of such a unit, as well as the terminology used to identify it, differs depending upon the type of engine.

In 2-stroke cycle engines, the passage which conducts intake air to the cylinders is generally called an AIR BOX. The air box surrounds the cylinders (fig. 5–1) and, in

many cases, is built into the block. (See item 7, fig. 3–1.) In 2-stroke cycle, V-type, Diesel engines, the air box consists of the space (within the block) included between the two banks of the V-construction; and the open space between the upper and lower deckplates of each bank. (See fig. 3–4.) The scavenging air passage in a Fairbanks-Morse opposed-piston engine is referred to as the AIR RECEIVER. This compartment is at the upper part of the block, and surrounds cylinder liners. In some 2-stroke cycle engines, the passage which serves as a reservoir for intake air from the blower is called an AIR HEADER.

Drains are generally provided in air boxes, receivers, and headers to drain off any liquids that may accumulate. A slight amount of vapors from the air charge may condense and settle in the air box, or a small amount of lubricating oil may be blown into the air box as the piston passes the ports on the downstroke following the power event.

On some engines, the drains are vented to the atmosphere. In others, a special drain tank is provided to col-

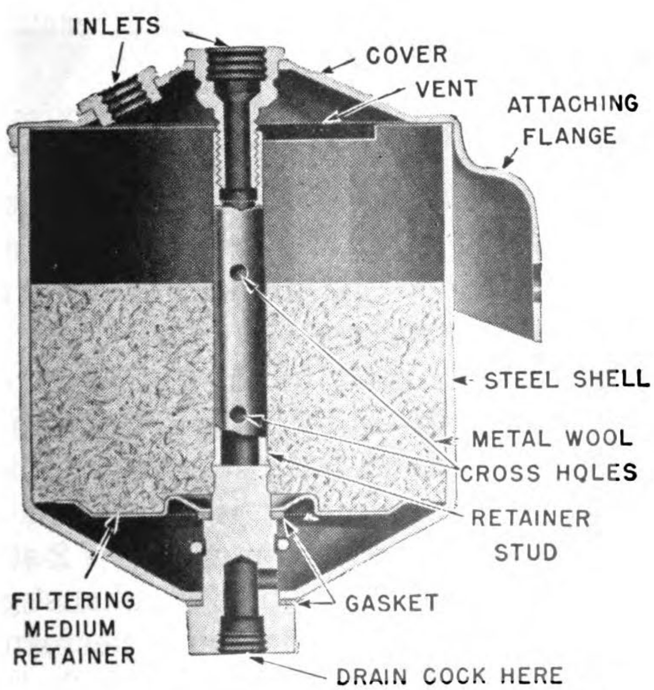


Figure 5–16.—Air box drain tank assembly (GM71).

lect the drainage from the air box. Figure 5–16 shows the air drain tank assembly for GM series 71 engines. The purpose of the tank is to prevent drainage of oil to the engine room. A small connection from the fuel pump also carries to the drain tank any fuel oil that may leak past the seals in the pump.

In 4-stroke cycle Diesel engines, the intake air passage from the blower to the cylinders differs, in general, from those in 2-stroke cycle engines in that the passage is not an integral part of the block. Instead, a separate unit is attached to the block for the purpose of conducting intake air to the engine cylinders. This attached unit is generally called the air intake MANIFOLD. Figure 5–17 shows the manifolds (both intake and exhaust) for the Cooper-Bessemer GSB-8 engine. Note the arrows which indicate the flow of air from the turbocharger, through the intake manifold, to the cylinders; and the flow of the gases from the cylinders back to the turbocharger and the exhaust.

The intake manifold shown in figure 5–17 is a one-piece fabricated steel unit. The unit is heavily insulated with felt lagging, heavy canvas, and water glass. The insulation serves to dampen the noise created by the turbocharger.

CYLINDER PORTS AND VALVES.—The admission of air to the cylinders from the air box or manifold is controlled by the opening and closing of the cylinder valves or ports. Since either or both of these items may be common to the exhaust system and the intake sytem of an engine, both are considered here.

Whether air is admitted to the cylinders of modern engines through ports or by valves depends upon the type of engine. In modern 4-stroke cycle engines, the admission of air to the cylinders is controlled by valves, while ports are used for this purpose in 2-stroke cycle engines. Ports control the discharge of exhaust gases from some 2-stroke cycle engines; and valves perform the same function in all 4-stroke and in many 2-stroke cycle engines.

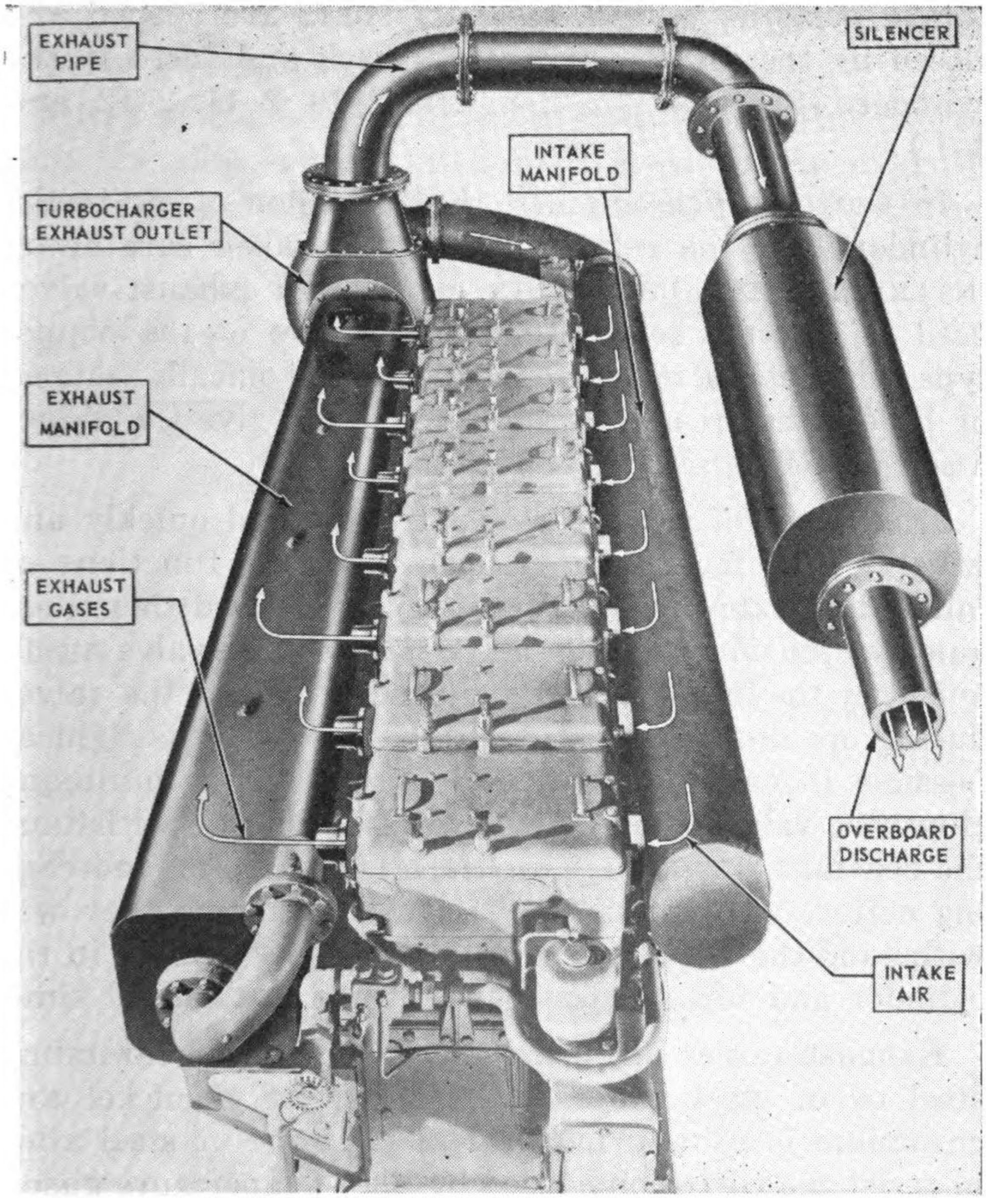


Figure 5–17.—Manifolds (GSB-8).

Frequent reference has been made in this course to ports and several figures have shown their location in the cylinder liner. (See figs. 2–8, 2–11, 2–13, 3–13, 3–17, 5–1, and 5–2.) INTAKE PORTS are generally located so as to give the air entering the cylinder a whirling motion. The turbulence created by this means helps to increase the amount of intake air reached by the injected fuel particles; thus, the power output of the engine is increased.

Intake ports as well as EXHAUST PORTS are opened and closed by the piston as it moves back and forth in the cylinder. (See figs. 2–2, 2–8, 2–9, 2–10, 2–11, 2–12, and 3–1.)

In 4-stroke cycle engines, the admission of air to the cylinders and the release of gases is taken care of by INTAKE and EXHAUST VALVES. Intake and exhaust valves used in internal combustion engines are of the poppet type. Poppet valves have heads with conically shaped or beveled edges and bevel seats, which give the valves a self-centering action.

The valves of an engine must be opened quickly and widely; they must remain open until the functions of intake and exhaust have been completed, and then close quickly. Considerable stress is created in the valve mechanism by the inertia forces required to operate the valves during opening and closing. Valves should be as light as possible in order to keep such stresses to a minimum. However, valves must be sufficiently strong to withstand the constant "pounding" caused by the opening and closing action. Valves must be so constructed that they will withstand the temperature and pressure occurring in the cylinder and form a gastight seal at the required time.

Exhaust valves are usually made of silicon-chromium steel or of steel alloys. A high content of nickel and chromium is usually included in the steel or steel alloy to resist the corrosion caused by high-temperature gases. A hard alloy, such as Stellite, is often welded to the seating surface of the valve head and to the tip of the valve stem. This hard alloy increases the wearing qualities of the surfaces which make contact when the valve closes. Low-alloy steels are generally used for intake valves, since these valves are not subject to the corrosive action of the hot exhaust gases.

A number of the figures already used in this course to illustrate other engine parts have also shown engine valves and related parts. (See figs. 3–12, 3–20, 3–23, and

5–1.) Another view of engine valves and their relation to other engine parts is shown in figure 5–18.

Note the shaded area of the exhaust valve. This represents metallic sodium. Sodium is used in the exhaust valves of some engines to aid in cooling the valves. The

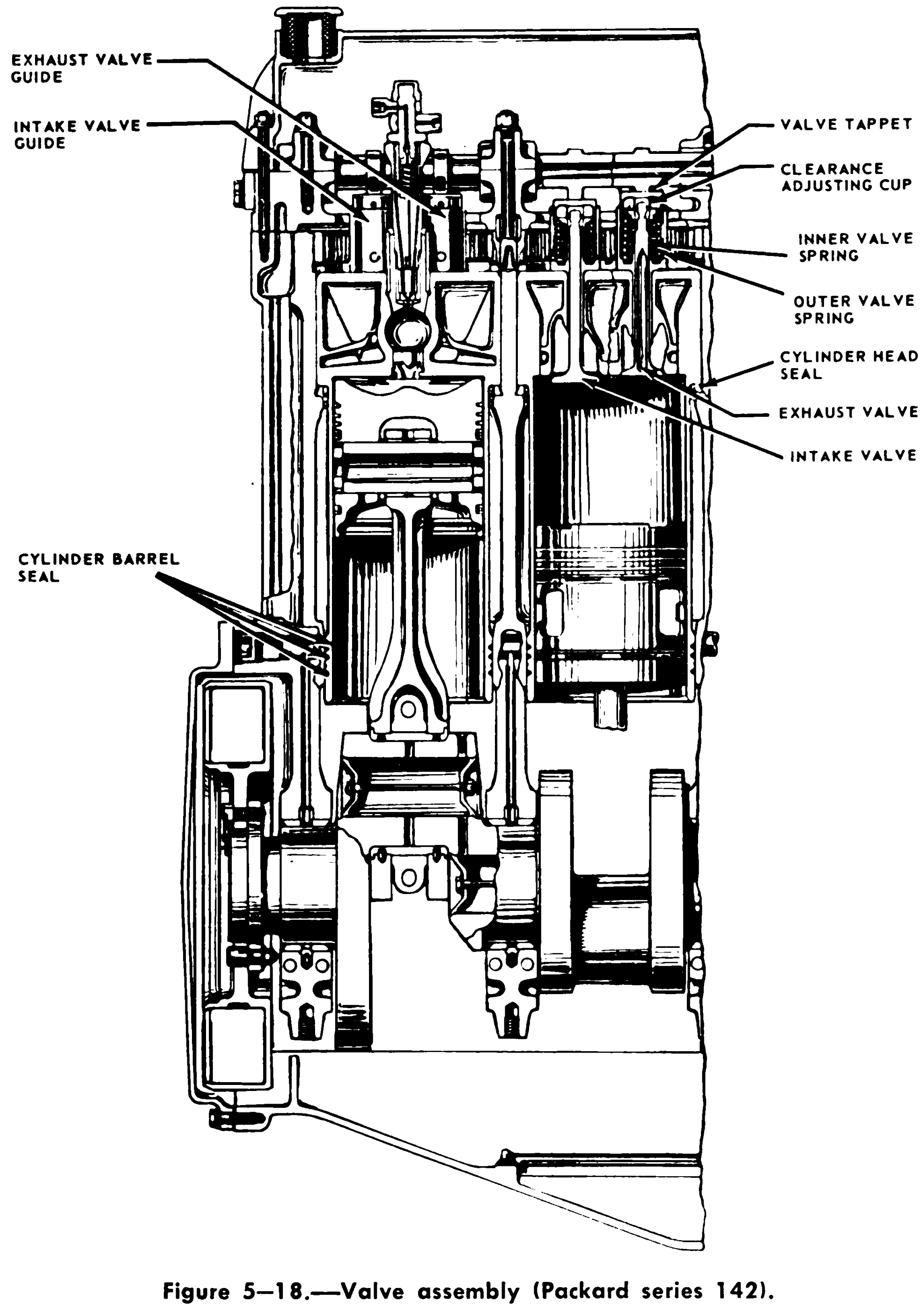


Figure 5–18.—Valve assembly (Packard series 142).

hollow valve stems are partially filled with sodium. At engine operating temperatures, the sodium melts and splashes up and down inside the valve. The sodium offers a very effective means of transferring the heat from the hot exhaust valve head through the stem and valve guides to the engine cooling system.

The valves of an engine are opened and closed at the proper point in the cycle of operation by a chain of parts which is frequently called the valve actuating mechanism or gear. Since the parts which drive valve actuating gear also drive parts related to other systems in many engines, information on actuating mechanisms and drive mechanisms is given in the next chapter.

CYLINDER TEST VALVES AND SAFETY OR RELIEF VALVES.—In some large engines, each of the cylinders is equipped with valves which serve different purposes from those of the valves discussed in the preceding section. Instead of admitting air to the cylinder or permitting the exhaust gases to escape, these valves may be of the type used for testing or they may be installed for safety purposes. Even though they are not a part of the engine's air system, these valves are definitely related to this system since they are provided to test or relieve pressure which may develop within the combustion space.

A valve which is used to vent the cylinder of any accumulated water or oil, before starting an engine; or one which is used to relieve the cylinder pressure when the engine is being turned by hand; or one which is used in connection with testing compression and firing pressures, is generally referred to as a TEST VALVE. Test valves are hand operated. (See fig. 5–19.)

The terms SAFETY VALVES and RELIEF VALVES are used by manufacturers to identify valves installed in cylinder heads or liners and designed to relieve excessive pressure which may be developed when the engine is operating. Whether called safety valves or relief valves, these valves are designed to open when the cylinder pressure exceeds a safe operating limit.

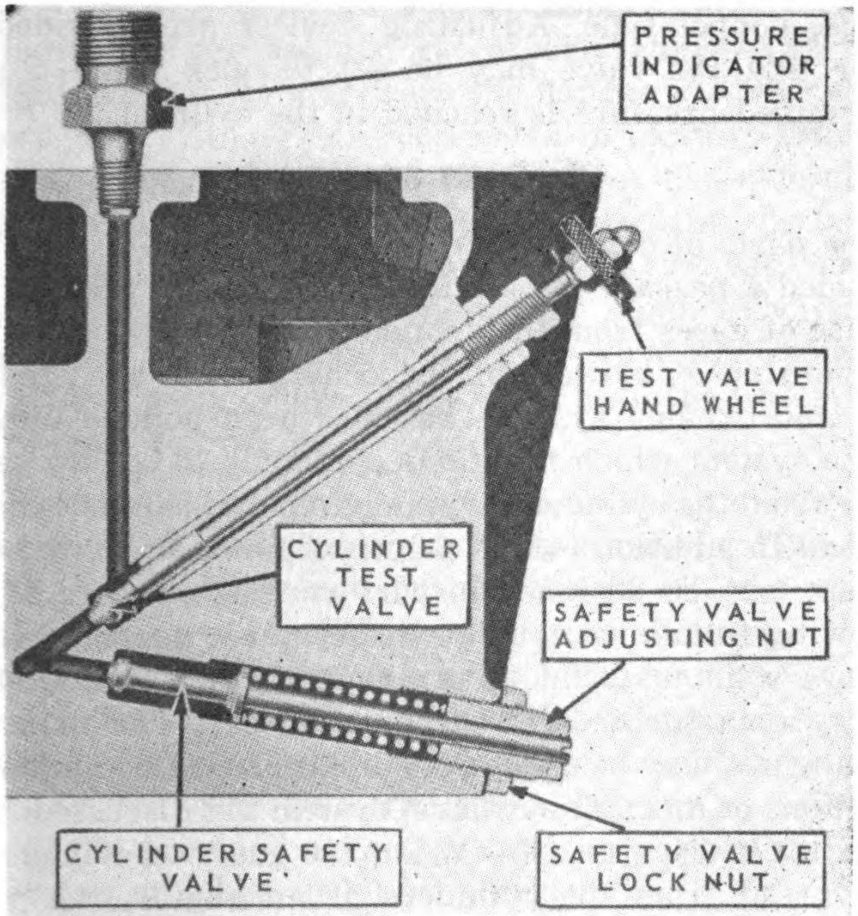


Figure 5–19.—Cylinder test and safety valves (GM268A).

A sectional view of the safety valve and test valve arrangement in the head of a GM268A engine is shown in figure 5–19. Note the passage and adapter for a cylinder pressure indicator. Most test and relief valve arrangements have an adapter for the cylinder pressure measuring instrument.

The valves shown in figure 5–19 are fitted in passages within the cylinder head. In several engines, however, the relief valve is a separate valve attached to the exterior of the head or liner. For example, the cylinder relief valve of an FM38D8 1/8 is screwed into an adapter which also provides a tapped opening for an indicator valve. The adapter is attached to the cylinder liner adapter sleeve.

Many cylinder safety or relief valves are of the spring

loaded, poppet type. Adjusting devices are provided in order that the valve may be set to open when a predetermined pressure is reached in the cylinder.

EXHAUST SYSTEMS

The parts of engine air systems considered so far have provided a passage for air into the cylinders and for the release of gases from the cylinders after combustion. The relationship of blowers of turbochargers to both the intake and exhaust systems has also been pointed out.

The system which functions primarily to convey gases away from the cylinders of an engine is called the exhaust system. In addition to this principal function, an exhaust system may be designed to perform one or more of the following functions: muffle exhaust noise, quench sparks, remove solid material from exhaust gases, and furnish energy to a turbine-driven supercharger. The principal parts which may be used in combination to accomplish the functions of an engine exhaust system are discussed here.

EXHAUST MANIFOLDS.—When the gases of combustion are forced from the cylinders of an engine, the gases enter a unit which is generally referred to as the MANIFOLD. The unit which receives the gases of combustion is sometimes called a header or belt. The interior of the exhaust manifold shown in figure 5–17 is illustrated in figure 5–20.

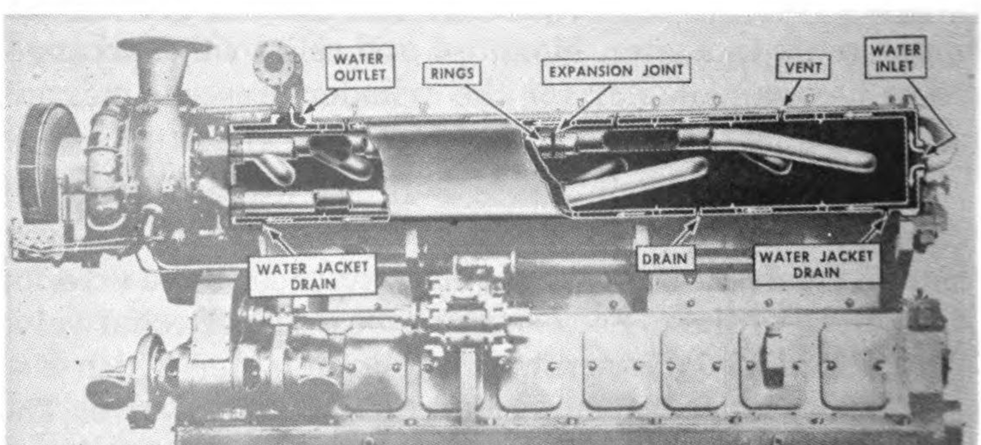


Figure 5–20.—Water-jacketed exhaust manifold (GSB-8).

The exhaust manifold of the Cooper-Bessemer GSB-8 is flanged to the exhaust valve ports (fig. 5–17) of the engine, with gaskets between the flanges and the cylinder heads. The cylinders are connected in pairs to four lines within the manifold. Each of the lines has a joint provided to allow for the expansion caused by the heat. A water jacket surrounding the bank of exhaust tubes reduces heat radiation into the engine room. (The exhaust manifolds of most marine engines are water cooled.) A protective resin compound is baked into the water jacket to prevent corrosion.

The manifold shown in figure 5–20 is a one-piece unit, fabricated of steel. Some manifolds are made of steel plate with welded joints and branch elbows of steel castings, while others are made of aluminum castings. In some cases, all exposed surfaces of exhaust manifolds and related parts are insulated with layers of spun glass held in place by laced-on woven asbestos covers. This insulation aids in reducing heat radiation. Expansion joints are generally provided between manifold sections and turbochargers or other outlet connections.

The exhaust manifold shown in figure 5–20 serves as the passage for the gases from the combustion spaces to the exhaust inlet of the turbocharger. Thus, the turbine end of the turbocharger may be considered as part of the exhaust system since it forms part of the passageway for the escape of gases to the exhaust outlet. (See figs. 5–13 and 5–17.) A similar arrangement is characteristic of other 4-stroke cycle, supercharged Diesel engines.

PIPING AND SILENCERS (MUFFLERS).—After passing through the turbine end of the supercharger of a 4-stroke cycle engine or after being discharged from the cylinders of a 2-stroke cycle engine, the gases pass through the EXHAUST PIPE, which may be flexible or rigid, to the SILENCER or muffler. The gases are discharged from the silencer to the atmosphere through the TAIL PIPE or OVERBOARD DISCHARGE PIPE. (See figs. 5–1 and 5–17.)

As the name implies, silencers or mufflers are provided on internal combustion engines principally to reduce the noise created by the exhaust as the exhaust valves or ports open. The noise of the exhaust could be reduced by placing sound-absorbent, flame-proof material in the exhaust passages, but the resulting back pressure might keep the engine from operating. Because of the serious effects of back pressure upon the operation of the engine, the device used to reduce the noise of the exhaust must be so designed that a minimum exhaust back pressure is created.

Most modern marine engines use an exhaust silencer of the WET type. A cutaway view of a silencer of this type is shown back in figure 5–1. The muffler shown in figure 5–17 is also of the wet type. Wet type mufflers are usually of cast or sheet iron construction, with a system of internal baffles which break up the exhaust gas pulsation. Thus, a silencing effect is obtained without producing a back pressure in the system. The water used in wet type silencers also aids in reducing noise. The water cools and shrinks the exhaust gases. This decrease in volume reduces the velocity of the exhaust gases and thereby reduces the exhaust noise. The water itself absorbs some of the sound.

The silencer shown in figure 5–1 consists of a steel drum which is divided into two compartments by a transverse baffle plate. The exhaust inlet pipe extends part way through the inlet compartment so that the exhaust gases must circle back, passing through a stream of water, before entering the pipes which extend through the baffle plate.

In the outlet compartment, the exhaust gases are again deflected before they enter the water outlet pipe. A second stream of water enters the tail pipe and helps carry the gases to the overboard discharge.

Some marine engines use a DRY type exhaust silencer. In both the wet and dry type silencers of most marine installations, circulating water is used to reduce the

temperature of the exhaust gases. The principal difference between the two is that in the dry type the exhaust gases do not come in contact with the cooling water; in other words, the water does not flow through the silencer compartment but flows, instead, through a jacket around the silencer. In wet type silencers the gases are expanded into the silencer and come in direct contact with the water. In passing through the baffles and through the water, the gases are cooled, condensed, decreased in volume, and effectively silenced.

In addition to acting as silencers, most mufflers also function as spark arresters. The water in wet type silencers serves as a spark arrester. In some dry type silencers, a device is incorporated to trap burning carbon particles and soot.

The interiors of all mufflers are subjected to moisture: condensation in dry type mufflers and the supplied water in mufflers of the wet type. Because of this, most silencers are coated inside and out with a corrosion-resistant material.

PARTS OF OTHER SYSTEMS RELATED TO ENGINE AIR SYSTEMS

The parts discussed in this chapter are those generally associated with the air systems of most engines. Some engines are equipped with parts which perform special functions. These parts, even though related to the engine air systems, are more frequently considered as parts of other engine systems.

For example, some engines are equipped with intake air heaters or utilize other methods to overcome the influence of low temperature in cold weather starting. Devices and methods used for this purpose are discussed in a subsequent chapter, which deals with engine operation and operating procedures.

Some engines are equipped with devices to cool the compressed air being discharged from the supercharger. Devices used for the cooling of air are considered in connection with engine cooling systems.

Many engines are equipped with devices or systems which function to provide crankcase ventilation. Blower action is necessary in many ventilation systems. The systems operate to prevent contamination of engine room space with heated or fume-laden air, to reduce the formation of sludge in lubricating oil, and to prevent the accumulation of combustible gases in the crankcase and in the oil pan or sump. The devices used to ventilate engine crankcases are considered in connection with lubricating systems.

SUMMARY

In Diesel engines, the passageway for air into and gases from the combustion spaces is formed by the parts of two systems—the intake and exhaust systems. The combustion spaces serve as the dividing line between the two systems.

The primary purpose of an intake system is to supply to the cylinders a large volume of low-pressure air for combustion. In addition, the system must clean the air and reduce the noise created by the air as it enters the engine. When the air has served its purpose in the cylinders, the waste gases are expelled to the atmosphere by the exhaust system.

You should know, in addition to the purpose of engine air systems, the purposes and principles of operation of the parts which are components of these systems. Be able to trace the path of intake air and exhaust gases through the air systems and know what occurs in each of the principal parts. Know the meaning and significance of scavenging and supercharging and be familiar with how these processes differ in the operating cycles of 2- and 4-stroke cycle engines.

QUIZ

1. What is meant by scavenging the cylinder of a Diesel engine?
2. In a 2-stroke cycle Diesel engine, the scavenging process takes place near what dead center?
3. What name is given to the process of increasing the amount of air available for combustion in engine cylinders?
4. During the scavenging process in both 2- and 4-stroke cycle engines, will the intake and exhaust openings be (a) both closed, (b) both open, (c) intake open and exhaust closed, or (d) exhaust open and intake closed?
5. Which of the fractions, 1/8, 1/4, 1/2, 1/20, 1/240, 1/360, represents the part of a crankshaft revolution during which supercharging takes place (a) in a 4-stroke cycle engine; (b) in a 2-stroke cycle engine?
6. In a 4-stroke cycle Diesel engine, does scavenging start before TDC or before BDC?
7. In both 2- and 4-stroke cycle engines, does supercharging take place when the piston is moving in an upstroke or in a downstroke?
8. What is the type of operating cycle if scavenging and supercharging both take place when the piston is in the vicinity of BDC?
9. In addition to cleaning a cylinder of exhaust gases, what other purpose does intake air serve during the scavenging process?
10. What is the principal difference between dry and viscous type air cleaners?
11. Does the air flow through the mesh or over the oil first in air cleaners of the oil bath type?
12. What causes air-borne particles to adhere to the surface of oil in oil-bath intake air cleaners?
13. What is the primary function of an engine blower?
14. Which of the two principal types of blowers is generally associated with 2-stroke cycle engines?
15. Of the two principal types of engine blowers, which type is not mechanically driven by the engine?
16. In an exhaust-driven turbocharger, does the impeller, rotate at the same speed as the turbine wheel?
17. What is the source of the oil used for the lubrication of a turbocharger?
18. What are the three principal things done to air as it passes from the atmosphere through the intake system to the cylinders of a supercharged engine?
19. What terms may be used to identify the air passage between the blower and intake ports of a 2-stroke cycle engine?

20. What are the sources of liquids which may accumulate in the air box of a 2-stroke cycle engine?
21. In what general way does the air passage between the blower and the cylinders of a 4-stroke cycle engine differ from that of a 2-stroke cycle engine?
22. The use of valves for both intake and exhaust is generally associated with engines operating on what type cycle?
23. Why are the exhaust valves of some engines filled with sodium?
24. Why are relief valves provided in the cylinders of some large engines?
25. Name two methods used to reduce heat radiation from exhaust manifolds.
26. What reduces the sound of exhaust gases as they pass through a silencer of the wet type?
27. What is the principal difference between silencers of the dry and wet types?
28. Arrange the following parts in proper order to show the path of air through an engine from air inlet to exhaust outlet: Valves, tail pipe, air box, muffler, blower, manifold, exhaust pipes, cylinders, cleaner, ports.
29. Is the list of parts given in the preceding question applicable to a 2-stroke cycle engine or a supercharged 4-stroke cycle engine? Why?

CHAPTER 6

OPERATING MECHANISMS FOR ENGINE PARTS AND ACCESSORIES

To this point, consideration has been given only to the main engine parts—stationary and moving—and to two of the systems common to internal combustion engines. At various points in the preceding chapters, reference has been made to the operation of some of the engine parts. For example, it has been pointed out that the valves open and close at the proper time in the operating cycle and that the impellers of a positive displacement blower rotate to compress intake air. However, little consideration has been given to the source of power or to the mechanisms which cause these parts to operate.

In many cases, the mechanism which transmits power for the operation of the engine valves and blower may also transmit power to parts and accessories which are components of various engine systems. For example, such items as the governor; fuel, lubricating, and water pumps; and overspeed trips, are, in some engines, operated by the same mechanism. Since mechanisms which transmit power to operate specific parts and accessories may be related to more than one engine system, such operating mechanisms are considered here before the remaining engine systems are discussed.

The parts which make up the operating mechanisms of an engine may be divided into two groups: the group which forms the DRIVE MECHANISMS; and the group which

forms the ACTUATING MECHANISMS. The source of power for the operating mechanisms of an engine is the crankshaft.

As used in this chapter, the term drive mechanism identifies that group of parts which takes power from the crankshaft and transmits that power to various engine components and accessories. In engines, the drive mechanism does not change the type of motion, but it may change the direction of motion. For example, the impellers of a blower are driven or operated as a result of rotary motion which is taken from the crankshaft and transmitted to the impellers by the drive mechanism, an arrangement of gears and shafts. While the type of motion (rotary) remains the same, the direction of motion of one impeller is opposite to that of the other impeller, as a result of the gear arrangement within the drive mechanism.

A drive mechanism may be of the GEAR, CHAIN or BELT type. Of these, the gear type is the most common; however, some engines are equipped with chain assemblies. A combination of gears and chains is used as the driving mechanism in some engines. Belts are not too common on marine engines, but are used as drive mechanisms on small engines.

Some engines have a single drive mechanism which transmits power for the operation of engine parts and accessories. In other cases, there may be two or more separate mechanisms. When separate assemblies are used, the one which transmits power for the operation of the accessories is called the ACCESSORY DRIVE. Some engines have more than one accessory drive. A separate drive mechanism which is used to transmit power for the operation of engine valves is generally called the CAMSHAFT DRIVE or TIMING MECHANISM.

The camshaft drive, as the name implies, transmits power to the camshaft of the engine. The shaft, in turn, transmits the power through a combination of parts which cause the engine valves to operate. Since the valves of

an engine must open and close at the proper moment (with respect to the position of the piston) and remain in the open and closed positions for definite periods of time, a fixed relationship must be maintained between the rotational speeds of the crankshaft and the camshaft. Camshaft drives are designed to maintain the proper relationship between the speeds of the two shafts. In maintaining this relationship, the drive causes the camshaft to rotate at crankshaft speed in a 2-stroke cycle engine; and at one-half crankshaft speed in a 4-stroke cycle engine.

The term actuating mechanism, as used in this chapter, identifies that combination of parts which receives power from the drive mechanism and transmits the power to the engine valves. In order for the valves (intake, exhaust, fuel injection, air starter) to operate, there must be a change in the type of motion. In other words the rotary motion of the crankshaft and drive mechanism must be changed to a reciprocating motion. The group of parts which, by changing the type of motion, causes the valves of an engine to operate is generally referred to as the VALVE ACTUATING GEAR or MECHANISM. A valve-actuating mechanism may include the cams, cam followers, push rods, rocker arms, and valve springs. In some engines, the camshaft is so located that the need for push rods is eliminated. In such cases, the cam follower is a part of the rocker arm. (Some actuating mechanisms are designed to transform reciprocating motion into rotary motion, but in internal combustion engines most actuating mechanisms change rotary motion into reciprocating motion.)

There is considerable variation in the design and arrangement of the parts of operating mechanisms found in different engines. The size of an engine, the cycle of operation, the cylinder arrangement, and other factors govern the design and arrangement of the components as well as the design and arrangement of the mechanisms. Some of the variation in operating mechanisms are considered in the descriptions and illustrations which follow.

Even though there are other arrangements of operating mechanisms, those described in this chapter are representative of those commonly found in marine engines of the Navy.

OPERATING MECHANISMS FOR A 2-STROKE CYCLE, IN-LINE, DIESEL ENGINE

As mentioned earlier, the operating mechanisms of some engines consist of a single-drive mechanism and the valve actuating mechanism. The 6-cylinder, GM 71 engine is used in this section as an example of an engine in which this is true. The single drive mechanism and the actuating gear are considered under the heading of operating mechanisms. As a complete assembly which transmits power from the driving part to the driven part, the operating mechanism of the GM 71 consists of gears, shafts, and couplings; and the parts of the valve-actuating mechanism.

GEARS.—When the driving mechanism of an engine consists only of gears, the mechanism is commonly referred to as a gear train. The gear train or drive for a GM 6–71 engine is shown in figure 6–1. The manufacturer designates the arrangement shown as being designed for right-hand rotation. (See figs. 3–1, 3–9, 3–19, and 5–1 for other views of parts related to this discussion.)

The gear train of a GM 71 functions as the camshaft drive as well as the accessory drive. The train consists of five helical gears, completely enclosed and located at the rear end of the engine. Note that all gears are driven by the CRANKSHAFT GEAR through an IDLER GEAR. The idler gear may be located on either the right or left side of the engine (see "dummy hub," sometimes called "spacer," fig. 6–1), depending upon the direction of crankshaft rotation.

Since the engine operates on the two-stroke cycle, the CAMSHAFT and BALANCER GEARS are driven at the same speed as the crankshaft gear. Either the camshaft gear or the balancer gear may be driven by the crankshaft gear

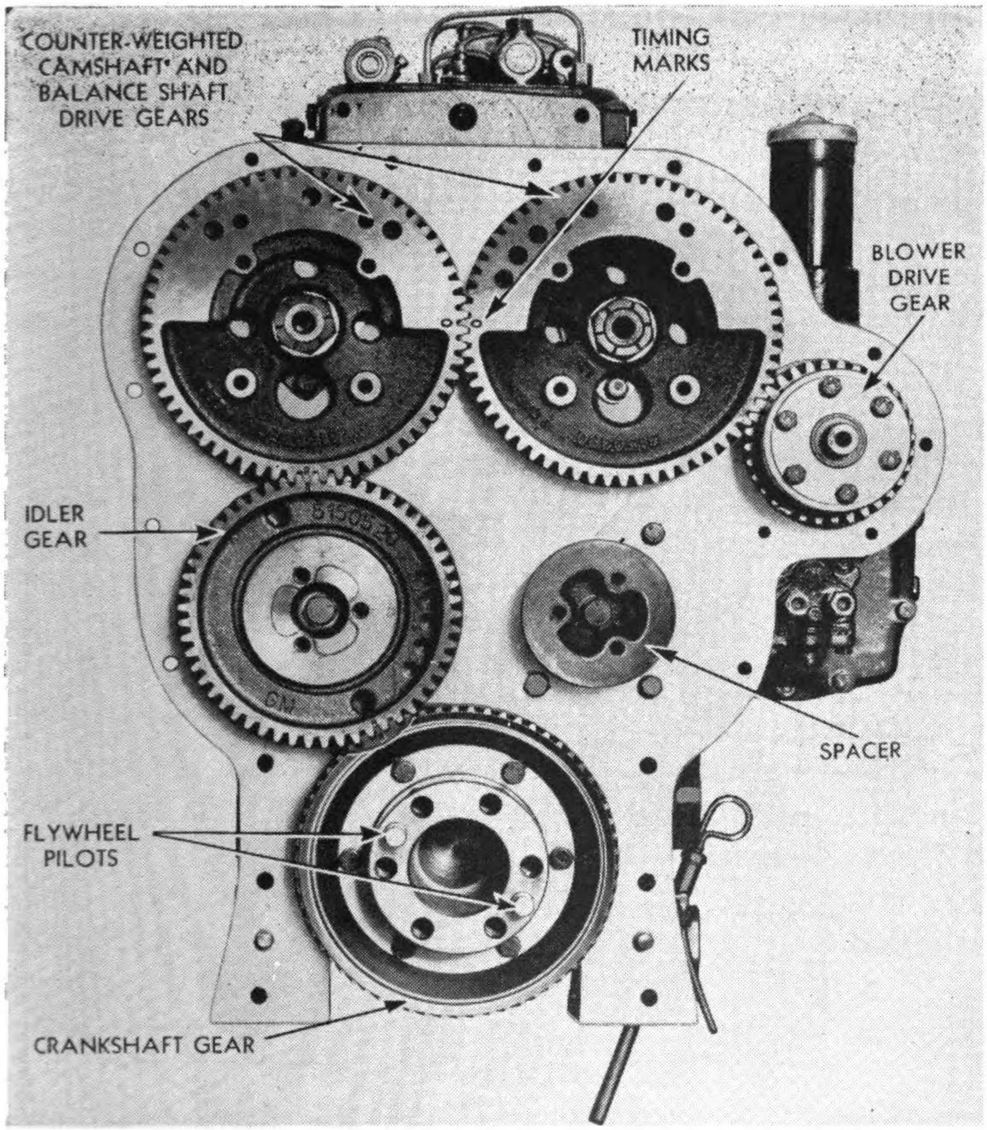


Figure 6–1.—Camshaft and accessory drive (GM 6–71).

through the idler gear, the drive arrangement depending upon the model (right- or left-hand rotation). The camshaft and balance shaft gears are counterweighted for balance purposes.

The accessories of the GM 71 receive power from the **BLOWER DRIVE GEAR** which is driven by the shaft drive gear (fig. 6–1). Located on the blower side of the engine and supported by the rear end plate (fig. 3–9), the blower drive gear transmits power not only to the blower but

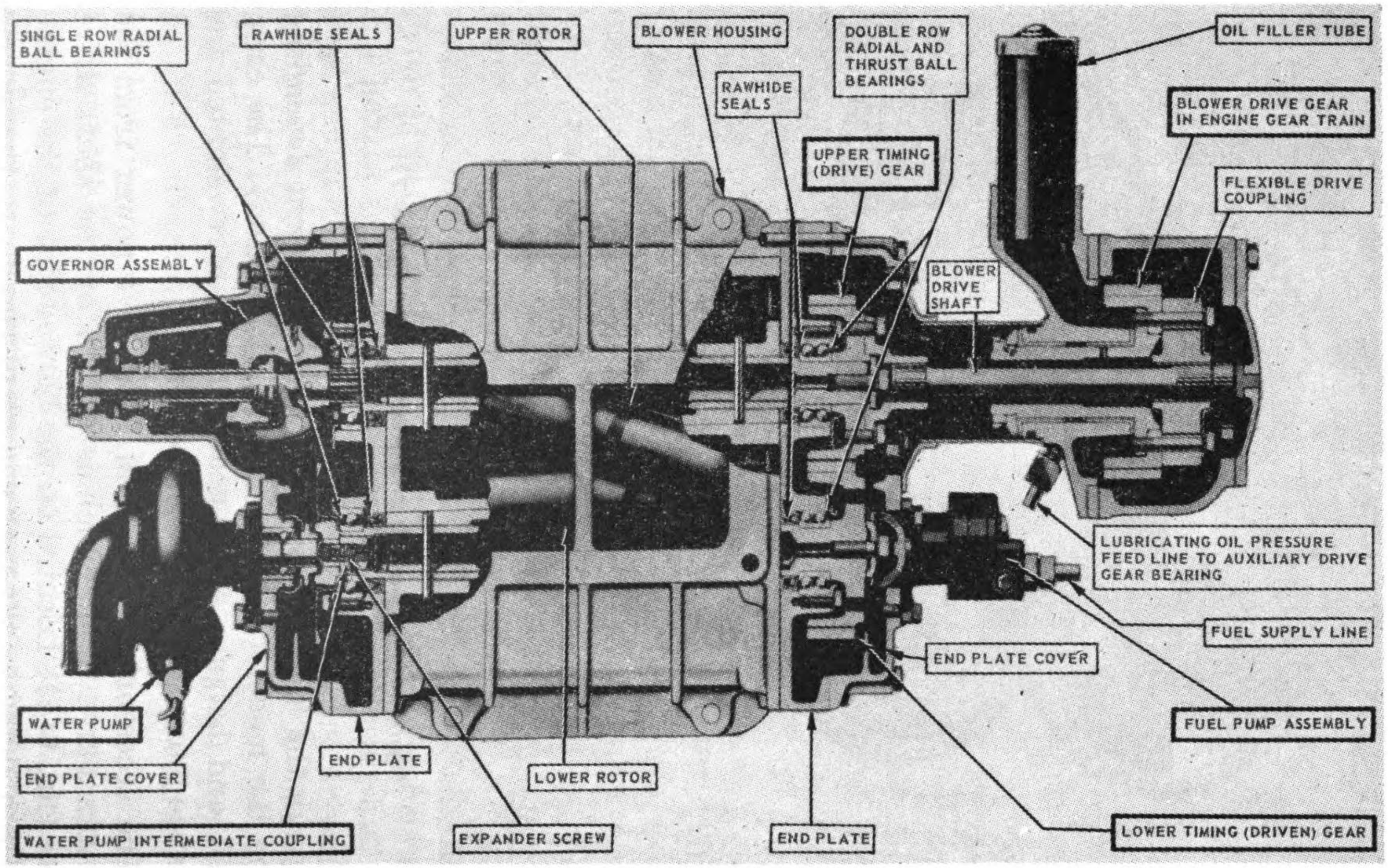


Figure 6–2.—Blower assembly with accessories attached (GM 6–71).

also to the governor, water pump, and fuel pump. (See fig. 6–2.)

Figure 6–2 shows the location of the various engine accessories and the shafts, gears, and couplings which transmit the power from the blower drive gear to each of the accessories. Reference to the figure will aid you in becoming familiar with how the power transmission is accomplished.

SHAFTS AND COUPLINGS.—The shafts driven by the camshaft and balance shaft gears are shown in figure 6–3. (See fig. 3–1 for shaft bore in the block, and figure 5–1 for location of shafts with respect to other engine parts.) While the shaft gears are not interchanged for a change in direction of engine crankshaft rotation, the shafts may be used on either side of the cylinder block, depending upon the direction of crankshaft rotation.

The CAMSHAFT operates the mechanism which actuates the exhaust valves and the fuel injectors. The shaft is a one-piece drop-forging, case-hardened at the cams and journals. The cam lobes are heat-treated to provide a hard, wear-resistant surface. A set of three cams is provided for each cylinder. End and intermediate bearings are copper-lead, steel-backed bushings.

The BALANCE SHAFT, which runs parallel to the cam-

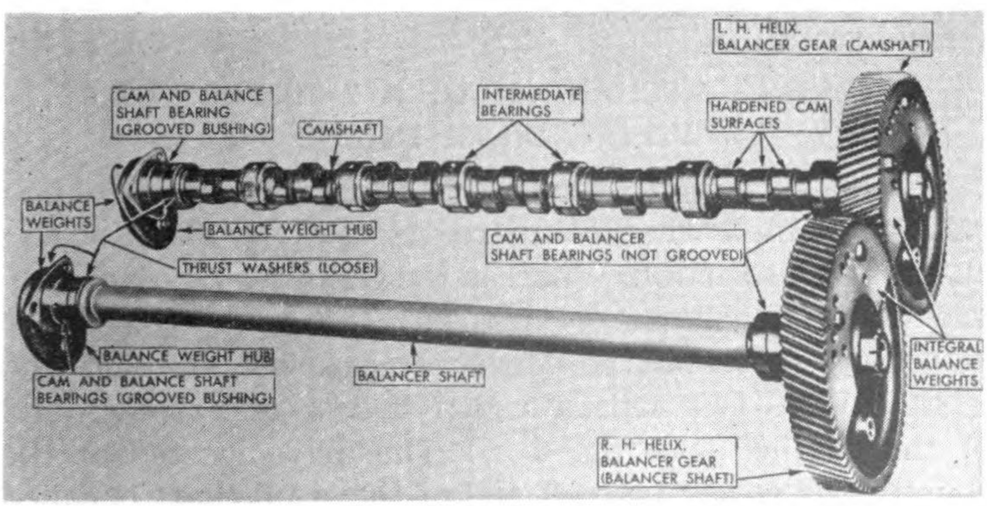


Figure 6–3.—Cam and balancer shaft assemblies (GM 6–71).

shaft on the opposite side of the block, is provided to counter-balance the rotation of the weighted camshaft and thus effect a stabilizing action upon oscillatory impulses developed within the engine. (See fig. 6–3 for location of balance weights.)

The blower end of the GOVERNOR DRIVE SHAFT is serrated and engages with corresponding serrations inside the upper blower shaft. The FUEL OIL PUMP is bolted to the rear endplate of the blower and is driven from the lower blower rotor shaft, through a device which acts as a UNIVERSAL JOINT. The WATER PUMP is mounted on the front end of the blower and is driven by the rotor shaft, through a COUPLING. (See fig. 6–2.)

VALVE-ACTUATING GEAR.—The exhaust valves and the fuel injectors are actuated by a mechanism which is located in and attached to the cylinder head. (See figs. 3–19 and 5–1.) A detailed view of the valve-actuating mechanism is shown in figure 6–4.

The insert shows the parts of the actuating mechanism for one cylinder. The mechanism includes three drop-forged ROCKER ARMS. The outer arms operate the exhaust valves and the inner arm operates the fuel injector. The rocker arms are actuated by the lobes of the camshaft, through PUSH RODS. These parts along with other parts essential to the assembly (fig. 6–4) change the rotary motion of the camshaft into the reciprocating motion of the valves.

OPERATING MECHANISMS OF A 2-STROKE CYCLE, V-TYPE, DIESEL ENGINE

The in-line engine discussed in the preceding section is relatively small when compared to the GM 16-278A discussed in this section. Whereas the GM 6–71 requires only one drive mechanism to transmit power to the valve-actuating gear and the engine accessories, the GM 16-278A utilizes two separate gear drives, one at each end of the engine. (See fig. 6–5.) The drive located at the coupling or power take-off end of the crankshaft is called the CAMSHAFT DRIVE. This drive transmits power to the

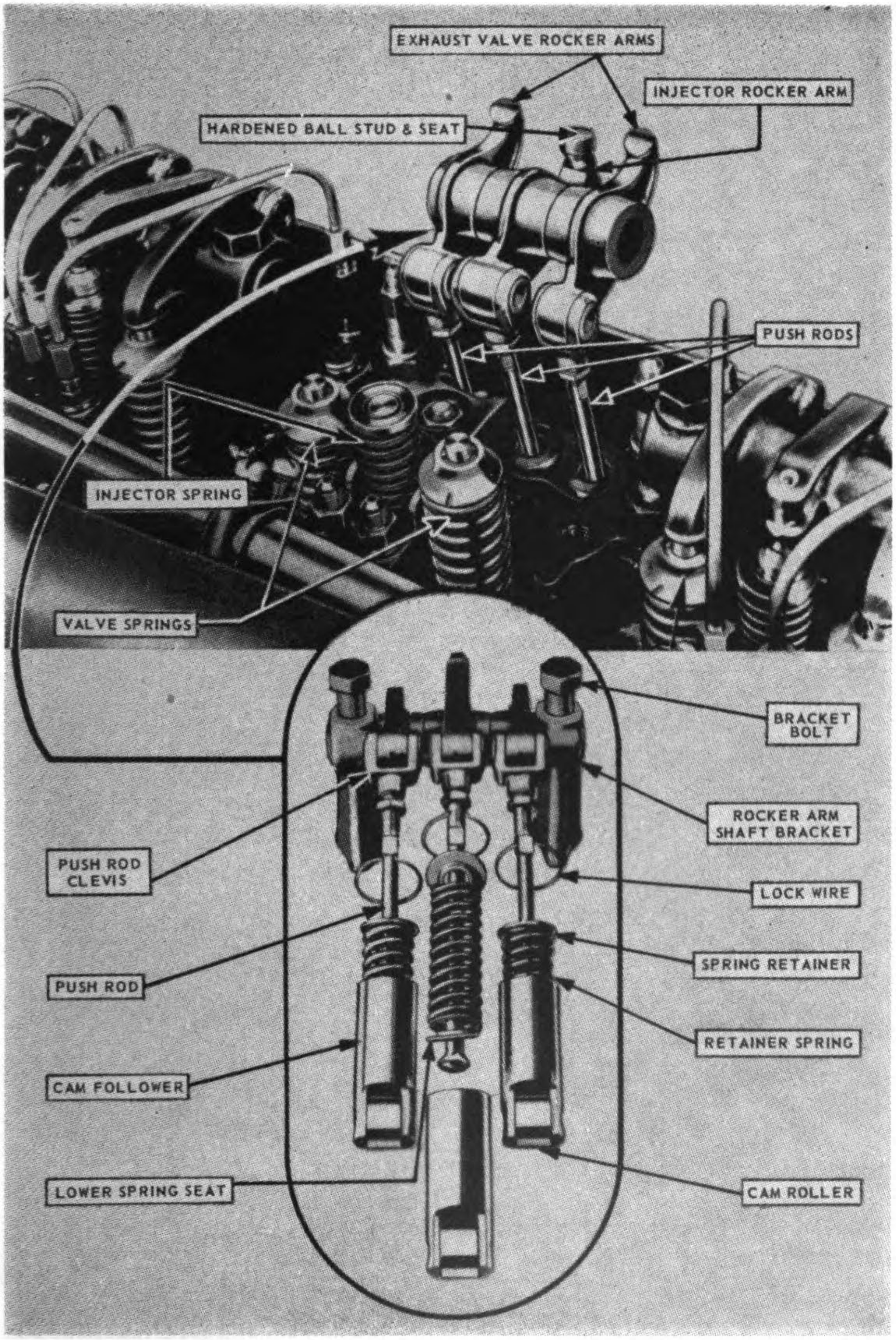


Figure 6–4.—Valve-actuating mechanism (GM 6–71).

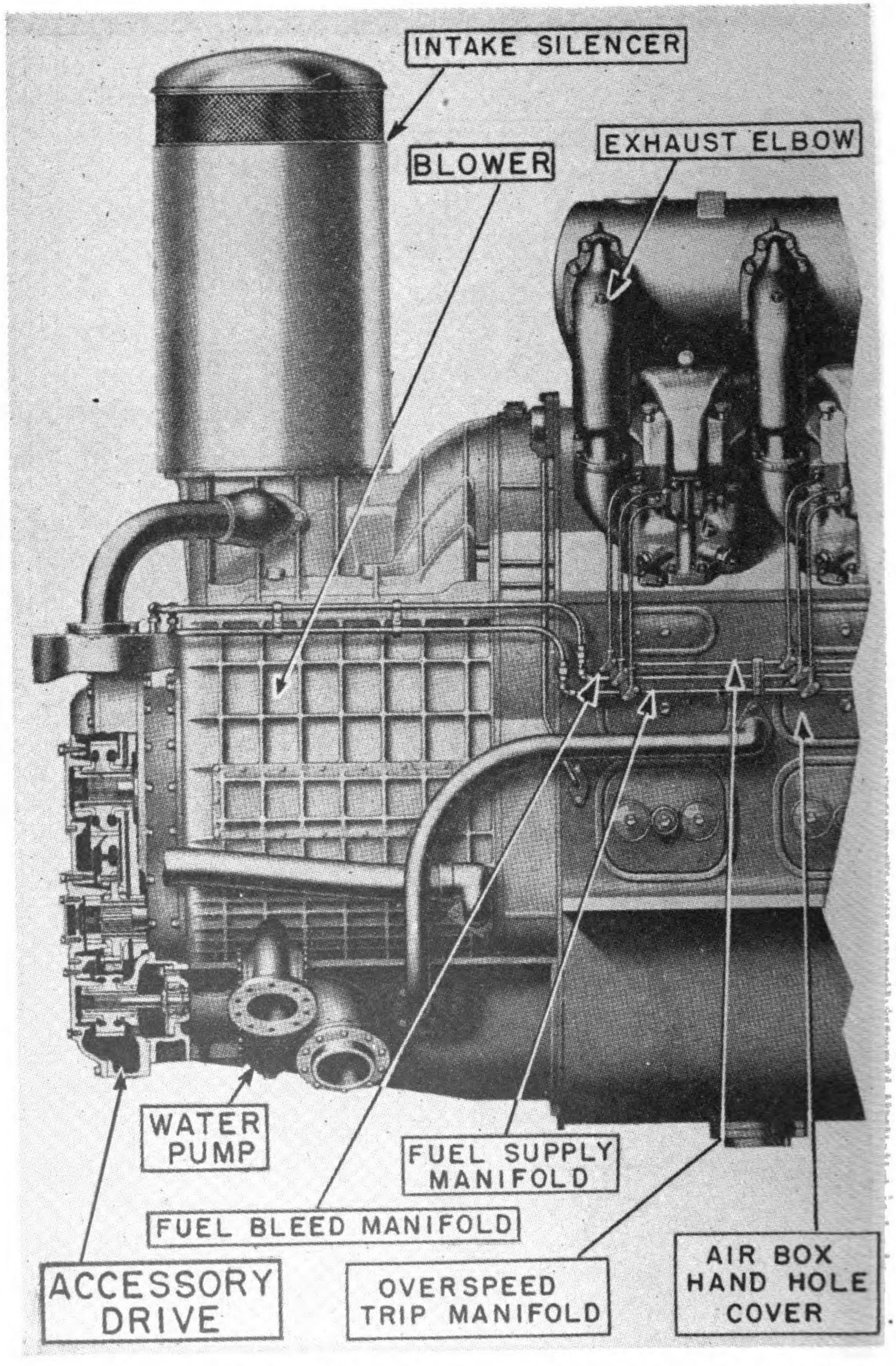


Figure 6–5.—Location of drive mechanisms in a V-type engine (GM 16–278A).

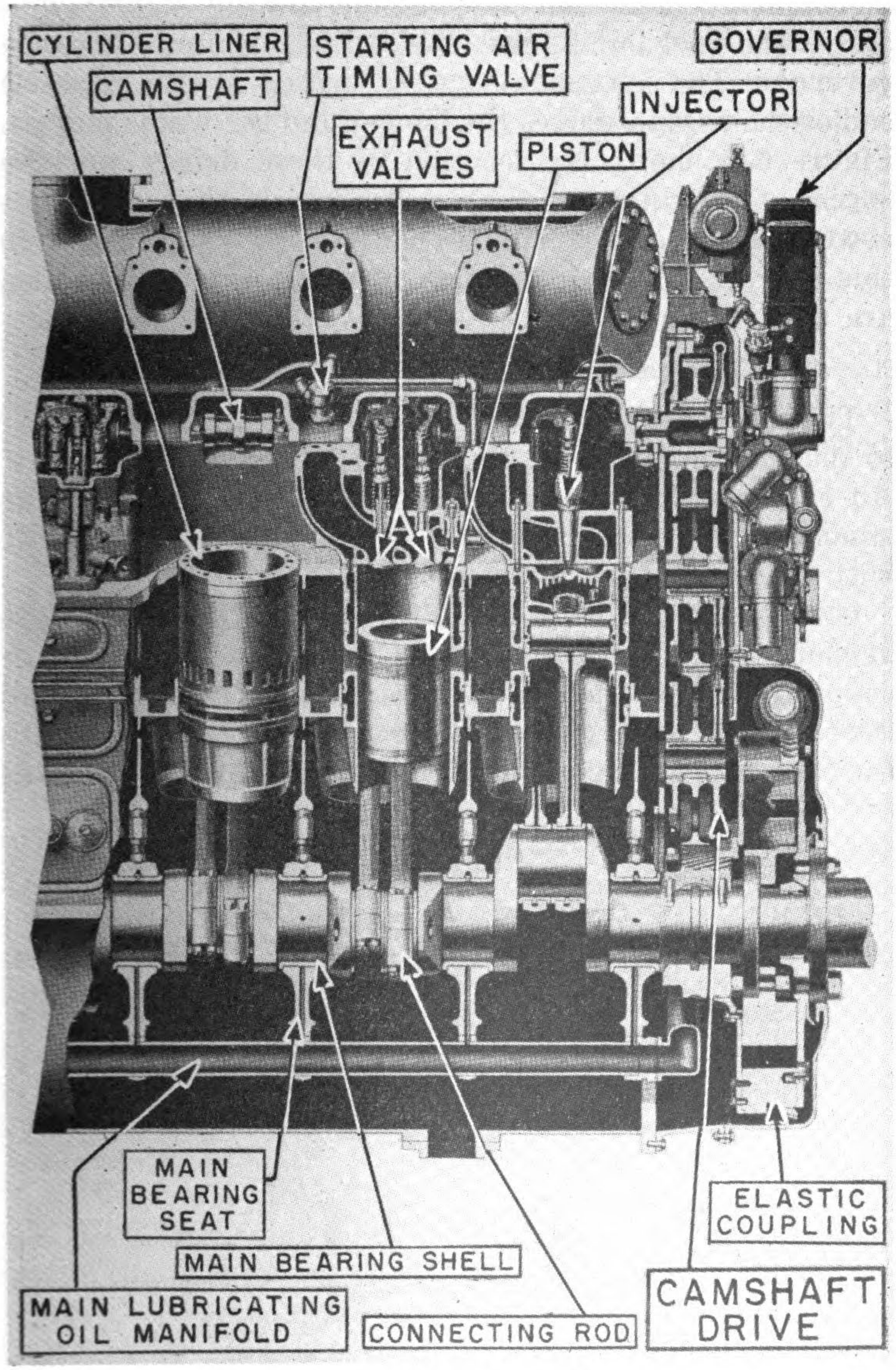


Figure 6–5.—Continued.

valve-operating mechanisms, the fuel injector operating mechanisms, and the starting-air timing valve; and drives the fuel pump, the lubricating oil pump, and the governor. The ACCESSORY DRIVE, located at the opposite end of the engine, drives the blower and the water pumps. Figure 6–5 shows the location of these drives and the engine parts and accessories to which they transmit power. Many of the engine parts already discussed in this course, and their location in this particular engine, are also shown.

Camshaft Drive and Valve-Actuating Gear

The camshaft gear train in the GM 16–278A is similar to that of the GM 6–71, except for two additional gears. An end view of the engine, showing the camshaft drive assembly, is given in figure 6–6. Compare this assembly with that of the GM 6–71, figure 6–1.

GEARS AND COUPLINGS.—Two CAMSHAFT GEARS are driven by the CRANKSHAFT GEAR at the power take-off or coupling end of the shaft, through the crankshaft and the camshaft IDLER GEARS. Both camshaft gears mesh with the camshaft idler gear. The LUBRICATING OIL PUMP GEARS

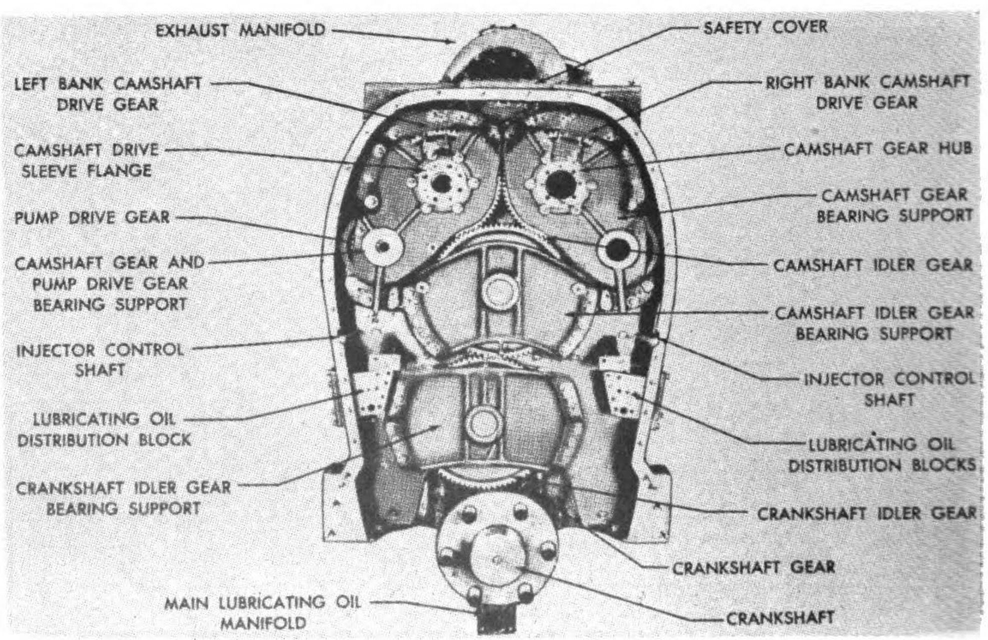


Figure 6–6.—Camshaft drive assembly, V-type engine (GM 16–278A).

are driven by the camshaft gears. A camshaft gear also furnishes power to drive the governor and the tachometer. In some models, the GOVERNOR DRIVE SHAFT is driven by the camshaft gear, through a FLEXIBLE COUPLING. In other models, the shaft is FLANGED and BOLTED to a camshaft gear.

The train of gears in the camshaft drive is enclosed in an oiltight housing. A spring-loaded safety cover is fitted to a pressure relief opening in the top of the housing. (See fig. 6–6.)

CAMSHAFTS.—Each cylinder bank of the engine is fitted with a camshaft. These shafts rotate at the same speed as the crankshaft but in the opposite direction. Each shaft is made of two sections which are flanged and bolted together. The cams are case-hardened and are an integral part of each shaft section. As is true of the GM 6–71, three cams are provided for each cylinder. In the GM 16–278A, however, push rods are not required for the transmission of power.

ROCKER ARMS AND VALVE BRIDGES.—Each cylinder head of the GM 16–278A is fitted with three rocker arms or levers. The two outer arms operate the exhaust valves and the inner arm operates the fuel injector. Since there are four exhaust valves per cylinder, each exhaust valve rocker arm, sometimes called a lever, must operate a pair of valves. This is accomplished by the use of a valve bridge. (See fig. 6–7.)

A valve bridge in this engine is made of forged steel and has a hardened ball socket into which the ball end of the rocker lever adjusting screw fits. A valve bridge has two arms, each of which fits over an exhaust valve.

The valve bridge spring keeps valve bridge tension off the valve stems until the bridge is actuated by the rocker arm. When the valve end of the rocker arm is forced down by the cam action, the valve bridge moves down, compressing the valve springs and opening the valves. By the time the action of the cam lobe has ceased, the valve springs will have closed the valves. The valve-operating

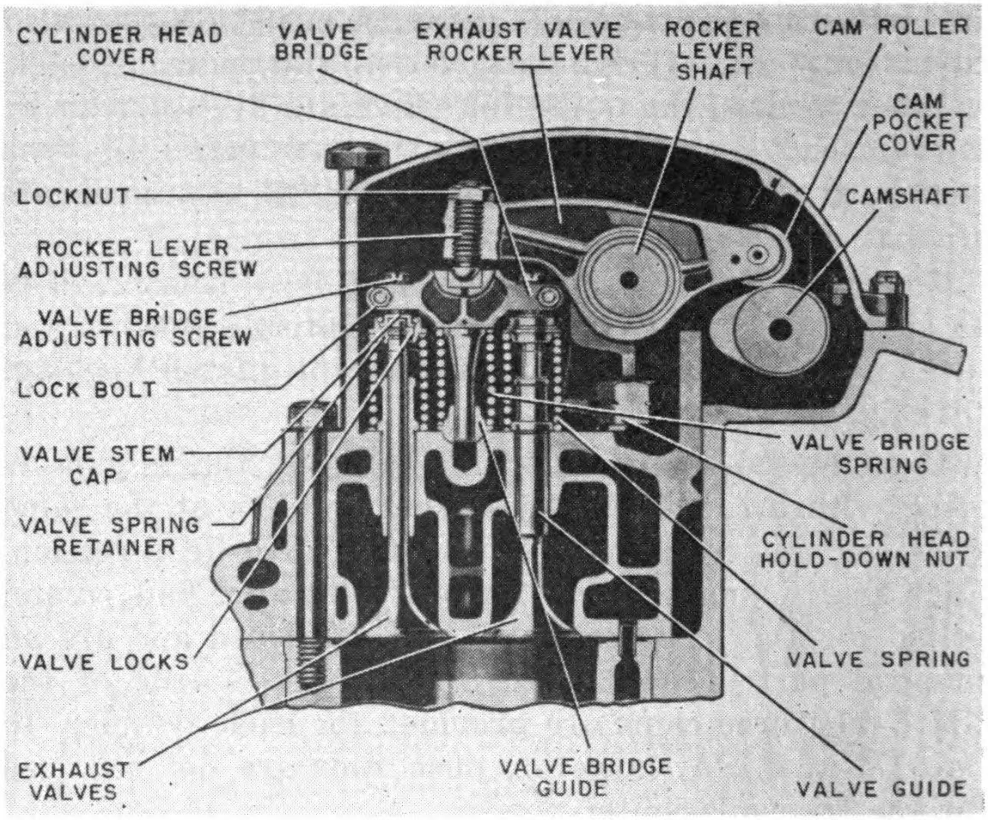


Figure 6–7.—Valve-operating mechanism with valve bridge (GM 16–278A).

mechanism illustrated in figure 6–7 is representative of those in which the location of the camshaft eliminates the need for push rods. Note that, in such cases, the cam lobes come in direct contact with the rocker arm cam rollers.

Accessory Drive

The gear train located on the front end of the engine (fig. 6–5) drives the blower and the water pumps. An end view of the assembly is shown in figure 6–8.

The train consists of helical gears of forged steel which transmit the rotation of the crankshaft to the blower and the water pumps. The assembly is enclosed in a case which is bolted to the blower housing. (See fig. 5–9.)

The drive gear is driven from the crankshaft through a splined shaft (fig. 5–9), one end of which fits into a hub that is bolted to the crankshaft while the other end fits into the blower drive gear hub.

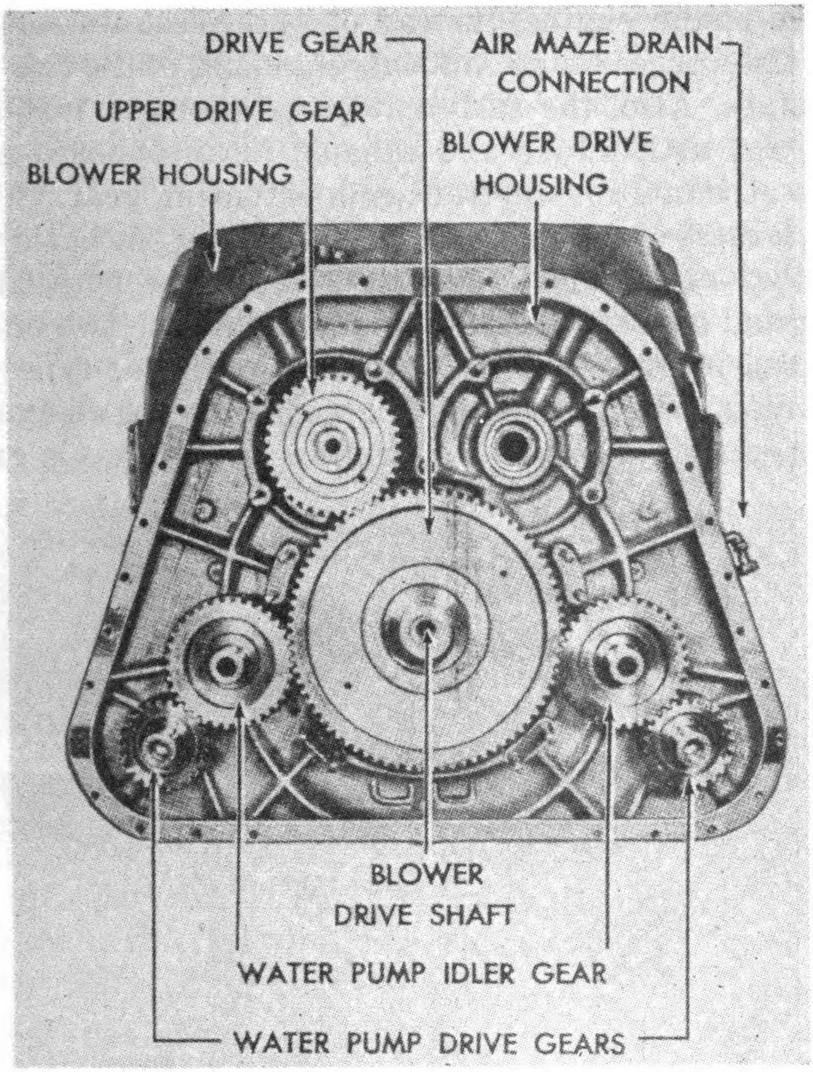


Figure 6–8.—Accessory drive mechanism (GM 16–278A).

The drive gear operates the water pump gears through idler gears and meshes directly with the upper drive gear. The upper drive gear transmits power through a shaft to the rotor-driven gear of the blower gear assembly. (See figs. 5–8, 5–9, and 5–10.)

OPERATING MECHANISMS IN AN OPPOSED-PISTON DIESEL ENGINE

The operating mechanisms of opposed-piston engines will obviously differ, to a degree, from those of single-acting engines, because of engine design differences. The fact that power is supplied by two crankshafts in an

opposed-piston engine, instead of one, accounts for some of the differences found in the mechanisms of the two types of engines. Also, the fact that ports are used instead of valves for both intake and exhaust in an opposed-piston engine accounts for differences in actuating gear.

Regardless of differences in mechanisms, the basic types of drives—gear and chain—are found in both single-acting and opposed-piston engines. While the two engines described in preceding sections had only gear-type drive mechanisms, the opposed-piston engine used as an example in this section and the single-acting 4-stroke cycle engine

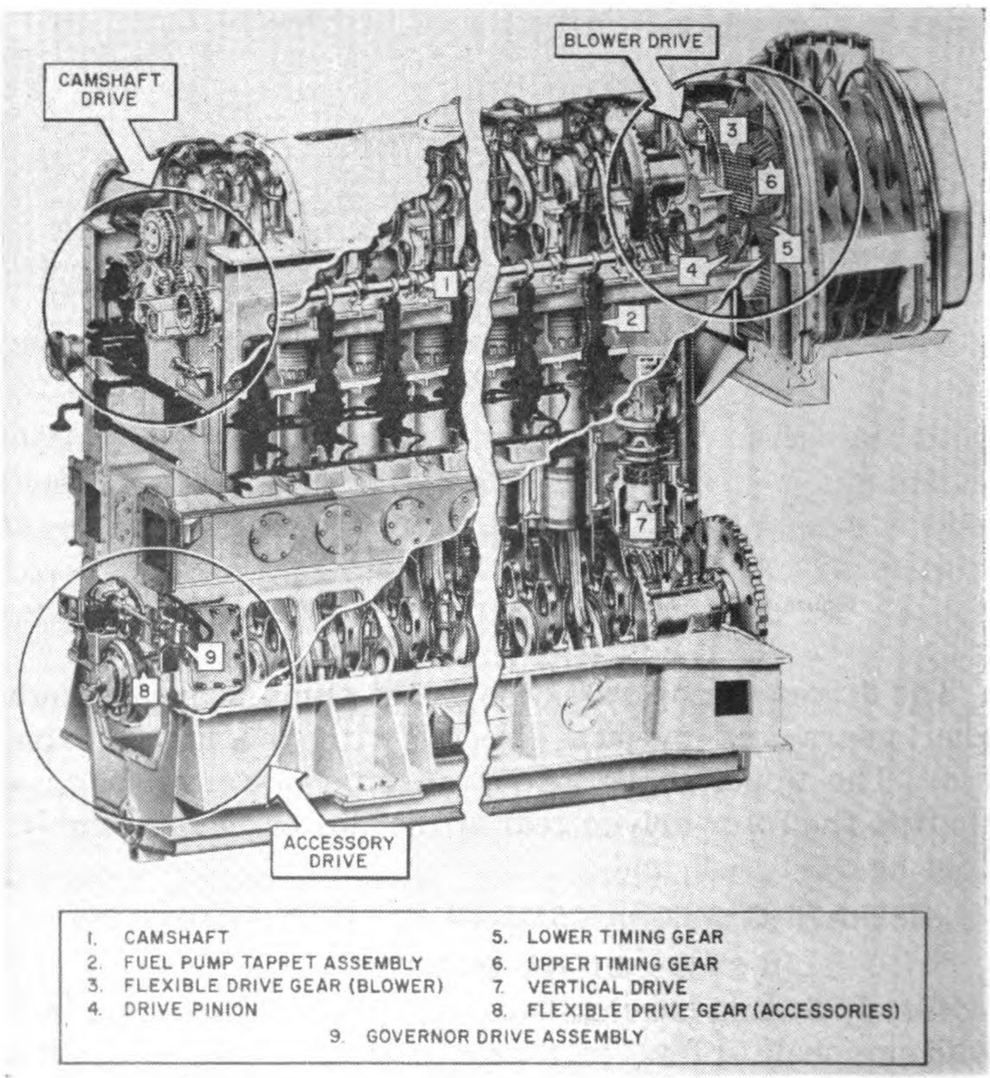


Figure 6–9.—Location of drive mechanisms in an opposed-piston engine (FM 38D8 1/8).

in the next section both have chain assemblies as well as gear trains incorporated in the mechanisms which supply power to engine parts and accessories.

The Fairbanks-Morse opposed-piston engine used as an example in this section has three separate drive mechanisms. The drive which furnishes power to the camshaft and fuel injection equipment is of the chain type. The blower and the accessories are operated by gear-type drives. The location of each drive is shown in figure 6–9.

Camshaft Drive and Fuel Pump Actuating Gear

The camshaft drives of the engines discussed in the preceding sections supply power to one or more accessories as well as to the valve-actuating gear. This is not true in the case of the drive in an FM 38D opposed-piston engine. Since the FM 38D does not have cylinder valves and since two other drives are provided to operate the accessories, the primary purpose of the camshaft drive is to transmit power for the operation of the fuel injection pumps.

CHAIN ASSEMBLY.—The power required to operate the fuel injection pumps at the proper instant during the cycle of operation is transmitted through the camshafts from the crankshaft by a CHAIN drive. This drive is frequently referred to as the timing mechanism. The names and arrangement of the components of the drive are shown in figure 6–10. The drive sprocket is attached to

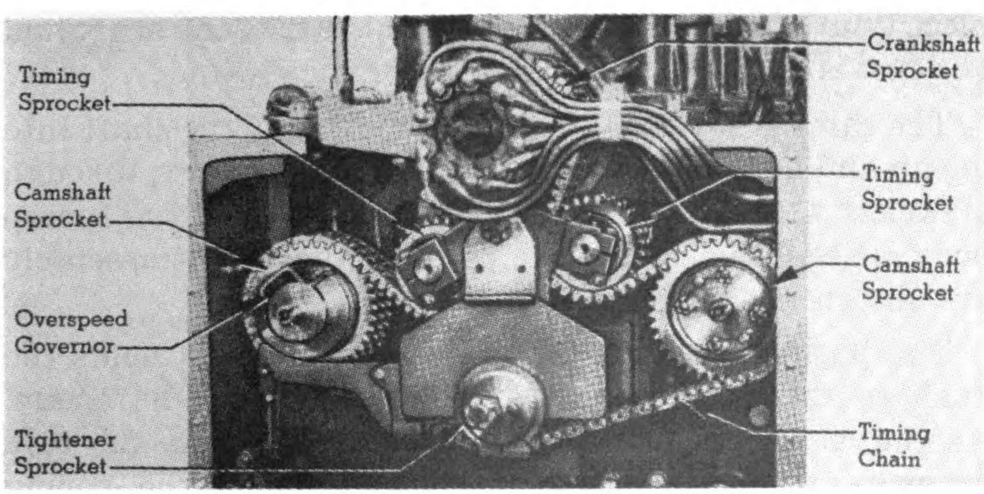


Figure 6–10.—Camshaft drive and timing mechanism (FM 38D8 1/8).

the upper crankshaft at the control end of the engine. A sprocket is attached to the end of each camshaft and three other sprockets are provided for timing and adjustment purposes.

The chain conveys the rotation of the upper crankshaft to the CAMSHAFT SPROCKETS by passing over the CRANKSHAFT SPROCKET, under the two TIMING SPROCKETS, over the two camshaft drive sprockets, and under the TIGHTENER SPROCKETS. The timing sprockets are mounted on an adjustable bracket or lever. By moving the lever, the timing of the two camshafts can be adjusted. The adjustable tightener sprocket provides a means of obtaining and maintaining the proper slack in the chain.

ACTUATING GEAR.—The CAMSHAFTS are located in the upper crankshaft compartment. (See 1, fig. 6–9.) Since engines of the opposed-piston type use ports for both intake and exhaust, the camshafts function only to actuate the two fuel injection pumps at each cylinder in unison and at the proper time. The shafts turn at the same rate of speed as the crankshaft.

The camshafts for the engine shown in figure 6–9 are of case-hardened alloy steel and are made in sections. The sections are made with match-marked flanges and are joined with fitted bolts. (In some opposed-piston engines made by the same manufacturer, the shafts are of the one-piece type.) The cams are an integral part of the shaft and one cam is provided on each shaft for each cylinder.

The cams transform the rotary motion of the shaft into the up-and-down motion of the fuel pump plunger, through a TAPPET ASSEMBLY attached to the top of the fuel pump body. (See 2, fig. 6–9.) The parts of the tappet assembly are shown in figure 6–11.

The push rod spring of the tappet assembly holds the push rod and the cam roller against the camshaft cam. As the camshaft rotates, the cam acts against the cam roller to force the push rod down against the spring tension and actuate the injection pump plunger.

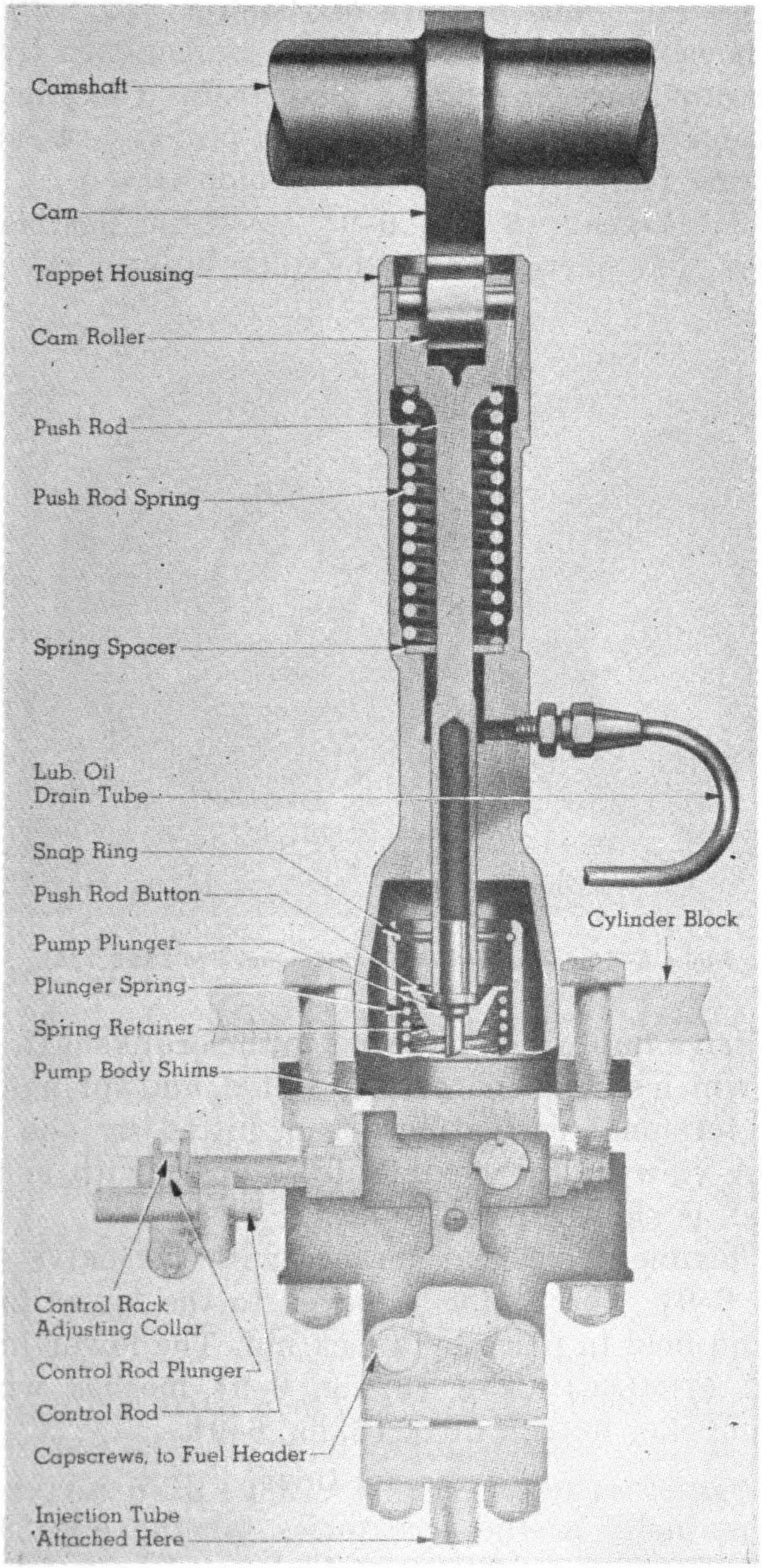


Figure 6—11.—Fuel pump tappet assembly (FM 38D8 1/8).

Blower Drive Mechanism

The power to drive the blower is transmitted from the upper crankshaft, through a gear train. (See fig. 6–9.) The train consists of a drive gear, a pinion gear, and the two timing (impeller) gears of the blower.

The drive gear (3, fig. 6–9) is of the flexible type. The principal parts of the FLEXIBLE DRIVE GEAR are: a

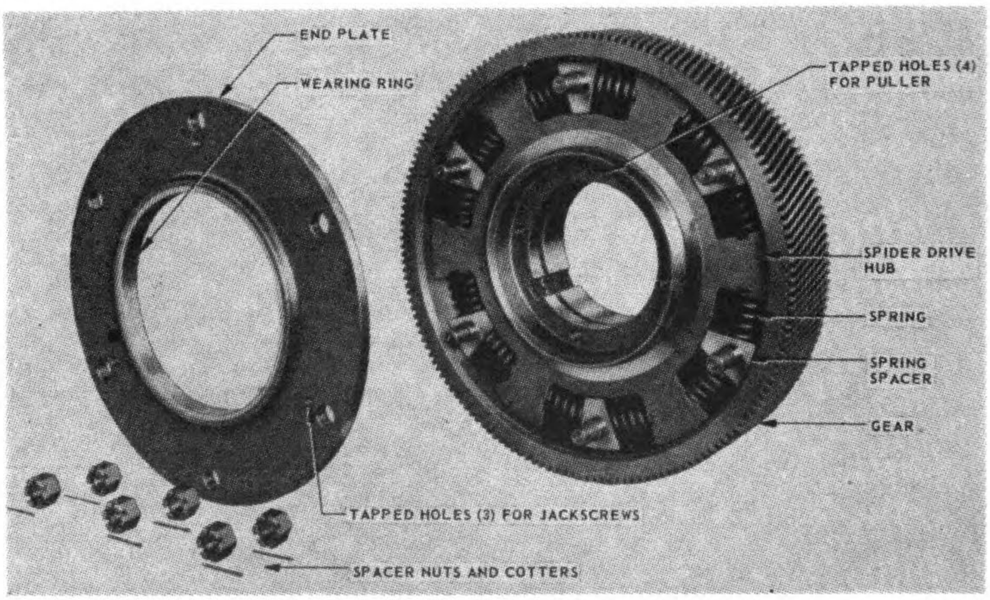


Figure 6–12.—Blower flexible drive gear (FM 38D8 1/8).

spider drive hub which is keyed to the crankshaft, a gear within which spring spacers are bolted, and springs which absorb torsional oscillations transmitted by the crankshaft. A view of the flexible drive gear, with end plate removed, is shown in fig. 6–12.

The flexible drive gear meshes with the DRIVE PINION (4, fig. 6–9). The pinion is keyed to the lower impeller shaft and held in place by a lock nut. The lower impeller DRIVING (TIMING) GEAR (5, fig. 6–9) meshes with the upper impeller DRIVEN GEAR (6, fig. 6–9).

Accessory Drive

The majority of the accessories for the FM 38D are driven by a gear mechanism which receives power from the lower crankshaft at the control end of the engine.

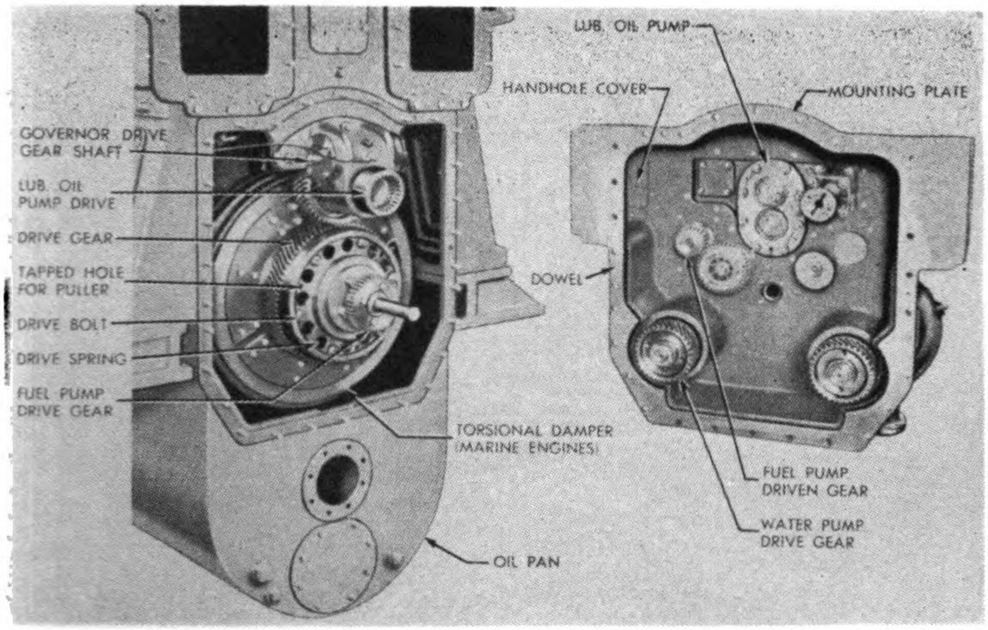


Figure 6–13.—Accessory drive (FM 38D8 1/8).

(See fig. 6–9.) A more detailed view of the accessory drive is shown in figure 6–13. Referring to both these figures as you read the following description will aid you in becoming familiar with the components of the drive and with the manner in which power is transmitted to the driven units.

The accessory drive transmits power to the water pumps, the fuel oil pump, the lubricating oil pump, and the governor. The DRIVE GEAR (8, fig. 6–9) of the mechanism is bolted to a flange on the crankshaft. The drive gear is of the flexible type; thus, engine shocks transmitted by the crankshaft are absorbed by the drive springs of the gear.

The WATER PUMP DRIVE GEARS mesh directly with the flexible drive gear. The FUEL PUMP DRIVE GEAR (attached to the flexible drive gear) transmits power to the FUEL PUMP DRIVEN GEAR through an IDLER. (See gear on mounting plate, fig. 6–13.) The LUBRICATING OIL PUMP DRIVE GEAR meshes directly with the flexible drive gear. Power is transmitted to the pump through a shaft and an internal gear coupling—the LUBRICATING OIL PUMP DRIVE. The

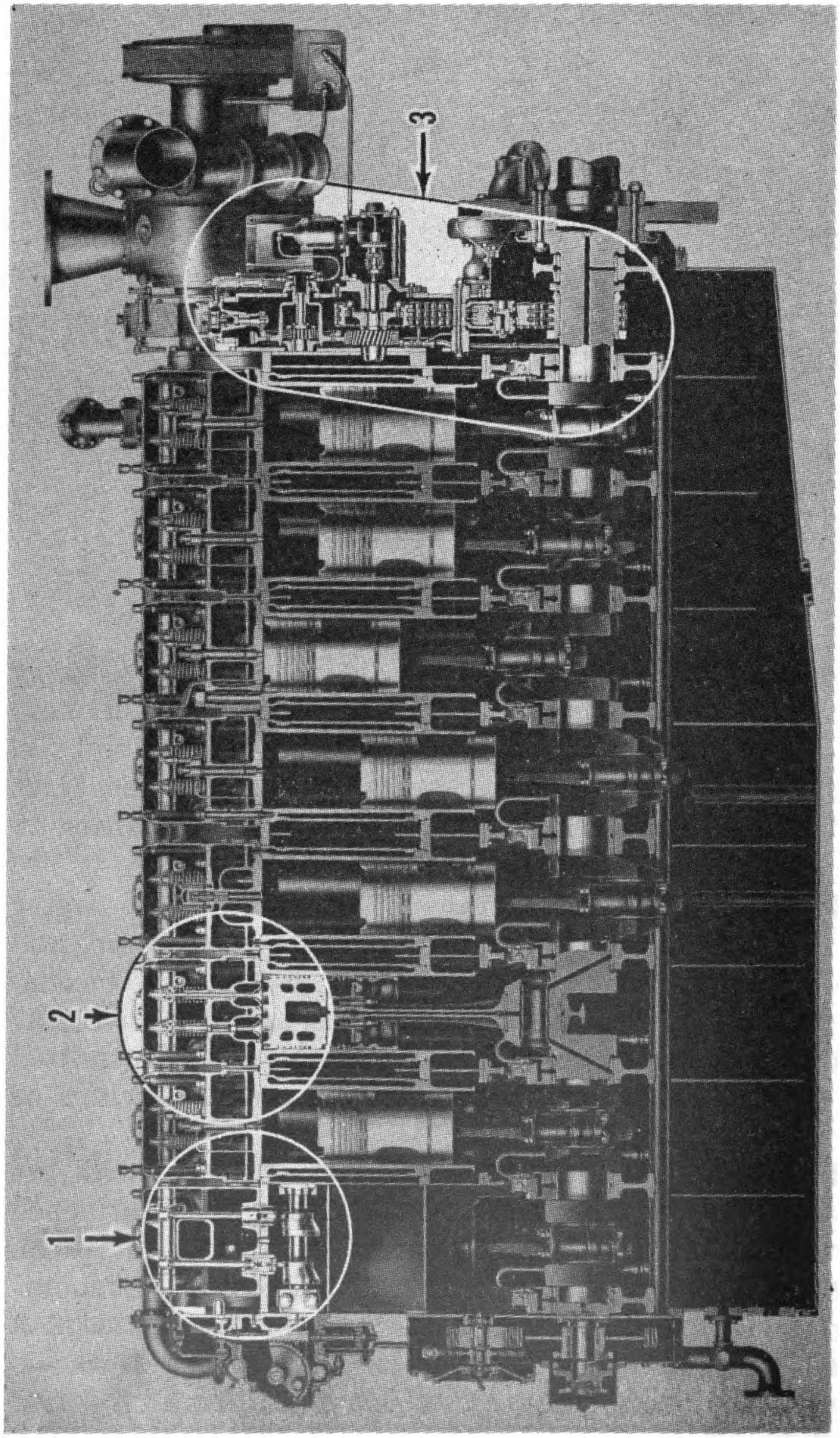


Figure 6—14.—Location of operating mechanisms (Cooper-Bessemer GSB-8).

shaft of the lubricating oil pump drive also transmits power to the governor. A gear on the shaft meshes with a mating gear on the GOVERNOR DRIVE GEAR SHAFT. This shaft drives the GOVERNOR COUPLING SHAFT which, in turn, drives the governor, through a BEVEL GEAR DRIVE. (See 9, fig. 6–9.)

OPERATING MECHANISMS OF A 4-STROKE CYCLE DIESEL ENGINE

The mechanisms discussed so far have been for 2-stroke cycle engines. The operating mechanisms of 4-stroke cycle engines are basically the same except for possible differences in design and arrangement and the reduced speed of the camshaft. The examples of operating mechanisms used in this section are those of the Cooper-Bessemer GSB–8, direct reversible, engine. The single-drive mechanism of this engine differs from those already discussed in that it consists of a combination of two types of drives. Also, the drive has no provision for driving a blower, since the supercharging unit is exhaust-driven. The valve-actuating gear differs, to a degree, from those discussed earlier in that valves are used for both intake and exhaust. The locations of the operating mechanisms are shown in figure 6–14.

Drive Mechanism

To this point, the drive mechanisms considered were either of the gear type or the chain type. The Cooper-Bessemer, GSB–8, utilizes a drive mechanism which includes a chain as well as gears. However, the primary drive or assembly which takes power from the crankshaft is a chain assembly. The relative arrangement of the chain assembly and the gears which form the drive are shown in figure 6–15.

CHAIN ASSEMBLY.—The chain (14, fig. 6–15) transmits power from the crankshaft sprocket (15) to the camshaft sprocket (7) and the knee sprocket (12). The camshaft sprocket is keyed to the fuel pump drive shaft and the knee sprocket is keyed to the lubricating oil pump drive shaft. Proper tension on the drive chain can be main-

tained by adjustment of the tightener (17) and idler sprocket (18).

GEARS AND SHAFTS.—The camshaft drive gear (8) is keyed on the fuel pump shaft and bolted to the camshaft sprocket. Bolt holes in the sprocket are elongated to permit slight rotation of the camshaft drive gear without moving the sprocket, when timing the camshaft. The camshaft drive gear drives the camshaft driven gear (10). The camshaft drive gear also drives the overspeed governor (3) and the tachometer generator (6), through the fuel pump shaft extension and bevel gears (4, 5, and 19). A bevel gear (9) is riveted to the side of the camshaft gear (10) and meshes with a bevel pinion (2) to drive the control governor (1).

The lubricating oil pump drive shaft transmits the rotation of the knee sprocket to the pump, through flexible couplings and an intermediate drive shaft. The lubricating oil pump drive shaft also transmits power to the water pump shaft, through helical gears (11 and 13).

Valve-Actuating Gear

In addition to furnishing power for the various engine accessories, the drive mechanism provides power for the operation of the engine valves, the fuel injectors, and the air pilot valve. The camshaft, the first main part in this group, receives power from the sprocket (7, fig. 6–15), though the two helical gears, (8) and (10). Since the engine operates on the 4-stroke cycle, there is a gear reduction between the camshaft drive gear and the camshaft driven gear, which causes the camshaft to rotate at one-half crankshaft speed.

CAMSHAFTS.—The ENGINE CAMSHAFT is located in the top side of the cylinder block. (See fig. 3–2 and 6–14.) The shaft is a one-piece steel tube, drilled for lubrication and fitted with individual removable cams. Two cams are provided for each cylinder, one for the intake valve roller assembly and the other for the exhaust valve roller assembly. The camshaft also carries the fuel injector

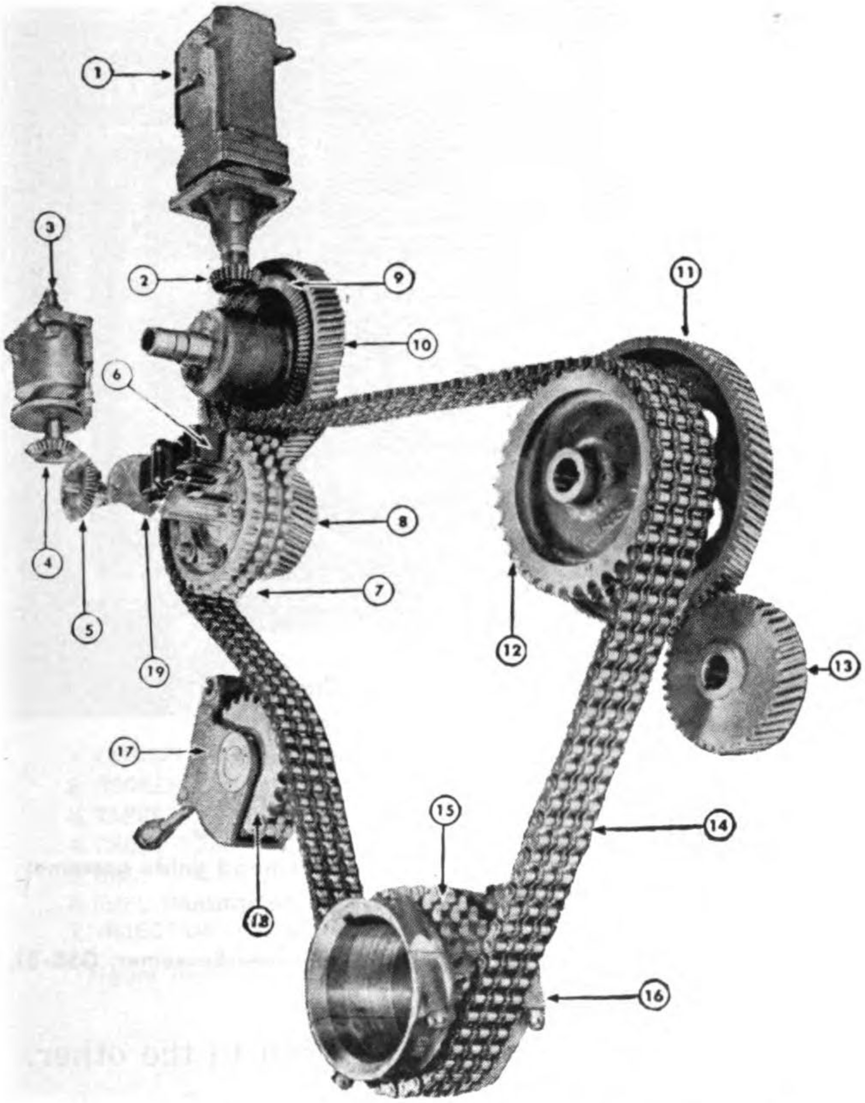
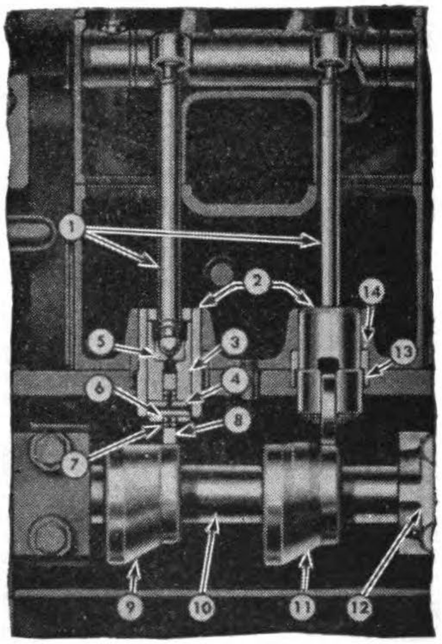


Figure 6–15.—Camshaft and accessory drive mechanism (Cooper-Bessemer, GSB-8).

gears, which drive the FUEL INJECTOR CAMSHAFT; and the pilot valve gear, which operates the PILOT VALVE CAMSHAFT of the air starting system.

CAM AND ROLLER ASSEMBLIES.—Since the GSB–8 is a reversible engine, its design is such that the engine camshaft can be shifted back and forth axially, for "ahead" and "astern" operation. The individual cams have lobes which are designed with positions for both directions of operation. A bridge between the lobes on each cam permits



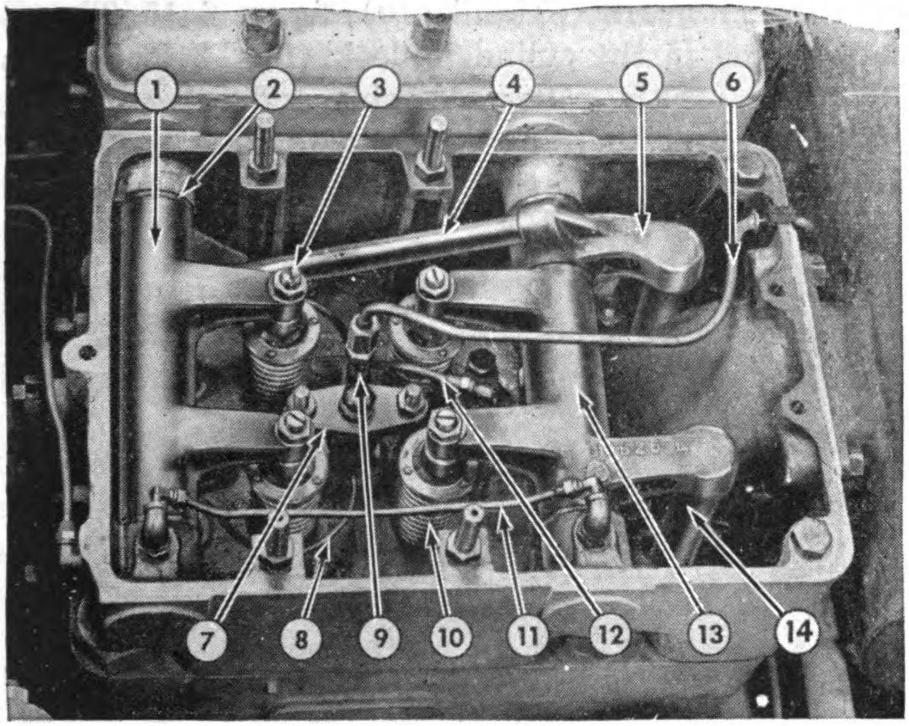
1. Pushrods
2. Crosshead guides
3. Crosshead
4. Roller pin
5. Push rod bearing
6. Roller collar
7. Roller bushing
8. Cam roller
9. Inlet cam
10. Camshaft
11. Exhaust cam
12. Bearing cap
13. Crosshead guide grommet
14. Guide spacer

Figure 6–16.—Cam and roller assemblies (Cooper-Bessemer, GSB-8).

the roller to "ride" from one position to the other. (See 1, fig. 6–14.)

A more detailed sectional view of the cam and roller assemblies for one cylinder is shown in figure 6–16. The parts shown are those which change the rotary motion of the camshaft into the reciprocating motion necessary to actuate the remainder of the valve gear located in the cylinder head.

VALVE GEAR IN CYLINDER HEAD.—The remaining parts of the valve-actuating gear and the valves are mounted in the cylinder head. (See fig. 3–20 and 2, fig. 6–14.) The various parts which are mounted in the cylinder head are identified in figure 6–17. Note the double arm rockers and the lack of a rocker arm for the fuel injection nozzle.



1. EXHAUST ROCKER
2. ROCKER BUSHING
3. TAPPET ADJUSTING SCREW
4. CROSS PUSH ROD
5. BELL CRANK
6. FUEL INJECTOR LINE
7. INJECTION NOZZLE FLANGE
8. INJECTION NOZZLE DRAIN
9. FUEL INJECTION NOZZLE
10. VALVE SPRING
11. LUBRICATING OIL JUMPER LINE
12. AIR STARTING LINE
13. INLET ROCKER
14. INTAKE PUSH ROD

Figure 6–17.—Valve-actuating assembly in cylinder head (Cooper-Bessemer, GSB-8).

Power Transmission from Crankshaft to Valves

The cross-sectional view of the GSB–8, figure 6–18, shows the principal parts of the valve-operating mechanism from camshaft to valves. Note the location of the mechanism with respect to other engine parts; and the relationship of the camshaft and roller assembly to the head-mounted parts. Using figure 6–18 and other illustrations dealing with the drive mechanism and valve-actuating gear of a GSB–8 as references, determine how part of the power developed in the engine cylinders is transmitted and utilized to actuate the engine valves.

Power taken from the crankshaft drives the chain assembly (3, fig. 6–14) which, in turn, rotates the cam-

shaft through gears (8) and (10), figure 6–15. The camshaft, located in the cylinder block (figs. 3–2, 6–14, and 6–18), actuates the roller assembly and valve push rods (fig. 6–16), and thereby transmits motion to the parts mounted in the cylinder head (figs. 6–17 and 6–18).

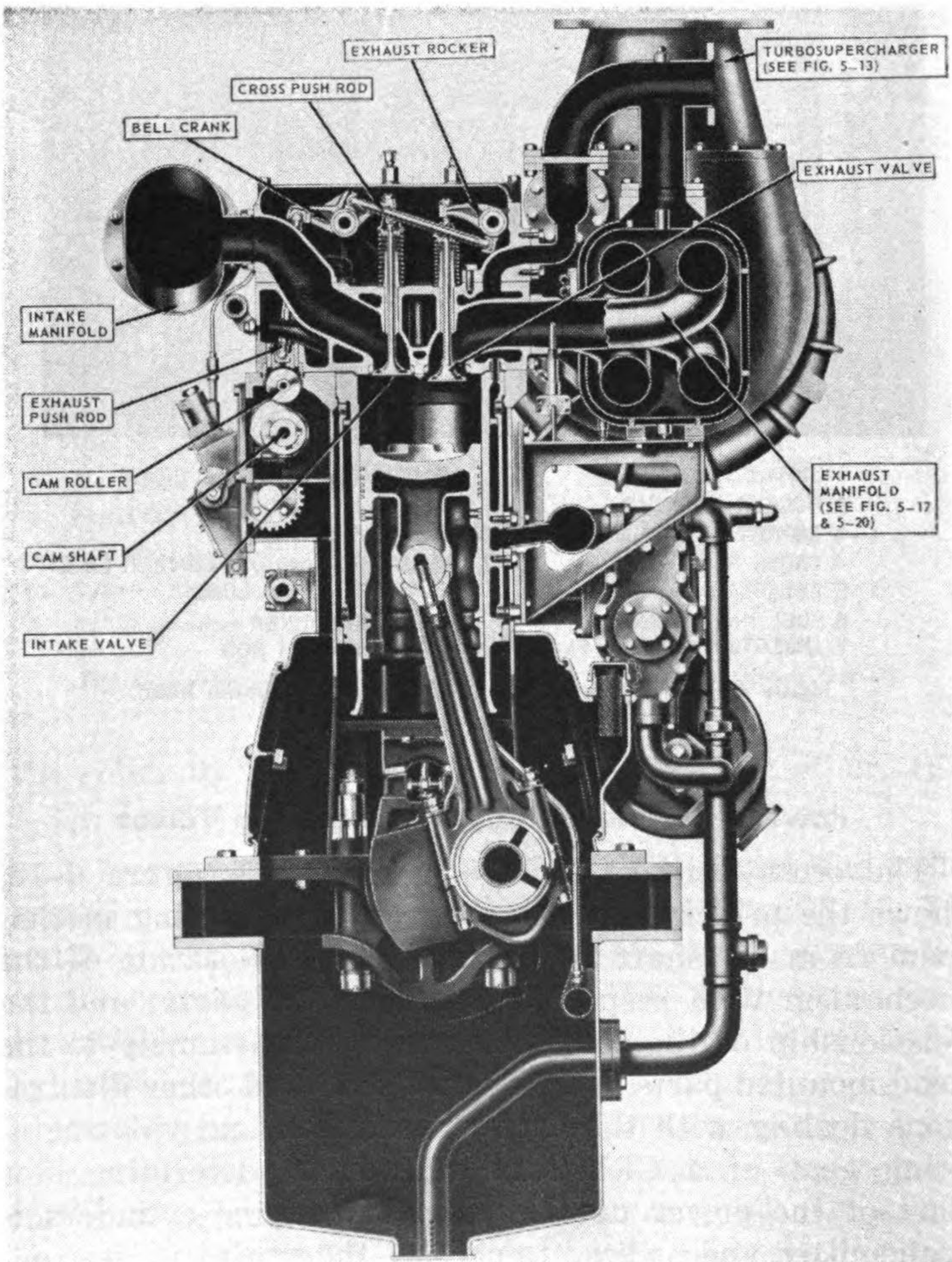


Figure 6–18.—Sectional view showing valve gear from camshaft to valves (Cooper-Bessemer, GSB-8).

Even though each cylinder has two intake valves and two exhaust valves, there is just one intake cam and push rod and one exhaust cam and push rod for each cylinder (fig. 6–16). As shown in figure 6–17 and figure 6–18, the intake valves are on the side nearest the camshaft and push rods.

When the push rod (14, fig. 6–17) moves up, it actuates the intake rocker (13), which pushes the two intake valves down. The exhaust valves are actuated by the push rod located under the bell crank (5). As the exhaust push rod moves up, motion is transmitted through the bell crank to the exhaust rocker (1), through the cross push rod (4). The cross push rod passes under the exhaust rocker and bears against a flange on the bottom side of the rocker (fig. 6–18). The counterclockwise motion of the bell crank, caused by the lifting of the exhaust push rod, results in clockwise motion of the exhaust rocker, which pushes the exhaust valves down to open.

If the cylinder head shown in figure 6–17 is rotated through 180° on its vertical axis and cross-sectioned through the valves, the view will be similar to that shown in figure 6–18. This figure shows the position of the parts at one point during the exhaust event. The piston is moving down, and the camshaft has brought the exhaust cam (11, fig. 6–16) under the exhaust roller assembly, forcing the exhaust push rod upward. The motion of the push rod has been transmitted through the bell crank, cross push rod, and exhaust rocker; and the exhaust valve is held open.

In addition to showing the valve and valve-actuating gear, figure 6–18 also shows other details of the engine. Several of the parts shown have been referred to in the discussion of engine parts. (See figs. 3–2, 3–8, 3–15, 3–20; 4–2, 4–8, 4–18.)

Lubrication of the various types of operating mechanisms is covered in a subsequent chapter, in connection with engine lubricating oil systems.

OPERATING MECHANISMS OF GASOLINE ENGINES

The mechanisms which supply power for the operation of the valves and accessories of gasoline engines are basically the same as those found in Diesel engines. Some manufacturers utilize mechanisms consisting primarily of chain assemblies, while others use gears as the primary means of transmitting power to engine parts. Combination gear-chain drive assemblies are used on some gasoline engines. In some cases, belts are used as driving mechanisms.

Even though the operating mechanisms of gasoline engines are similar to those found in Diesel engines, there are some differences in design and arrangement. Examples of some of the differences that may be encountered are illustrated in figures 6–19, 6–20, 6–21, and 6–22. The examples shown are not to be considered as typical of the operating mechanisms of all gasoline engines. As in the case of Diesels, there are many variations in design and arrangement of the operating mechanisms used in engines which operate on the Otto cycle. The examples shown provide a means for comparing the Diesel mechanisms discussed earlier in this chapter with those of the two gasoline engines used as examples in this section.

Actuating and Drive Mechanisms of a V-Type Gasoline Engine

The mechanisms illustrated in figures 6–19, 6–20, and 6–21 are those of the 4M–2500 Packard marine engine. The design and arrangement of mechanisms in the larger, Packard 1M–3300 are similar. By comparing the illustrations with views shown earlier of comparable Diesel engine parts, some of the ways in which the mechanisms of V-type gasoline engines differ from those of Diesel engines can be seen.

The top illustration in figure 6–19 shows a cross section of the valves and the actuating gear for one cylinder. The center illustration is an external view of a portion of the camshaft and rocker assemblies. At first glance, there is

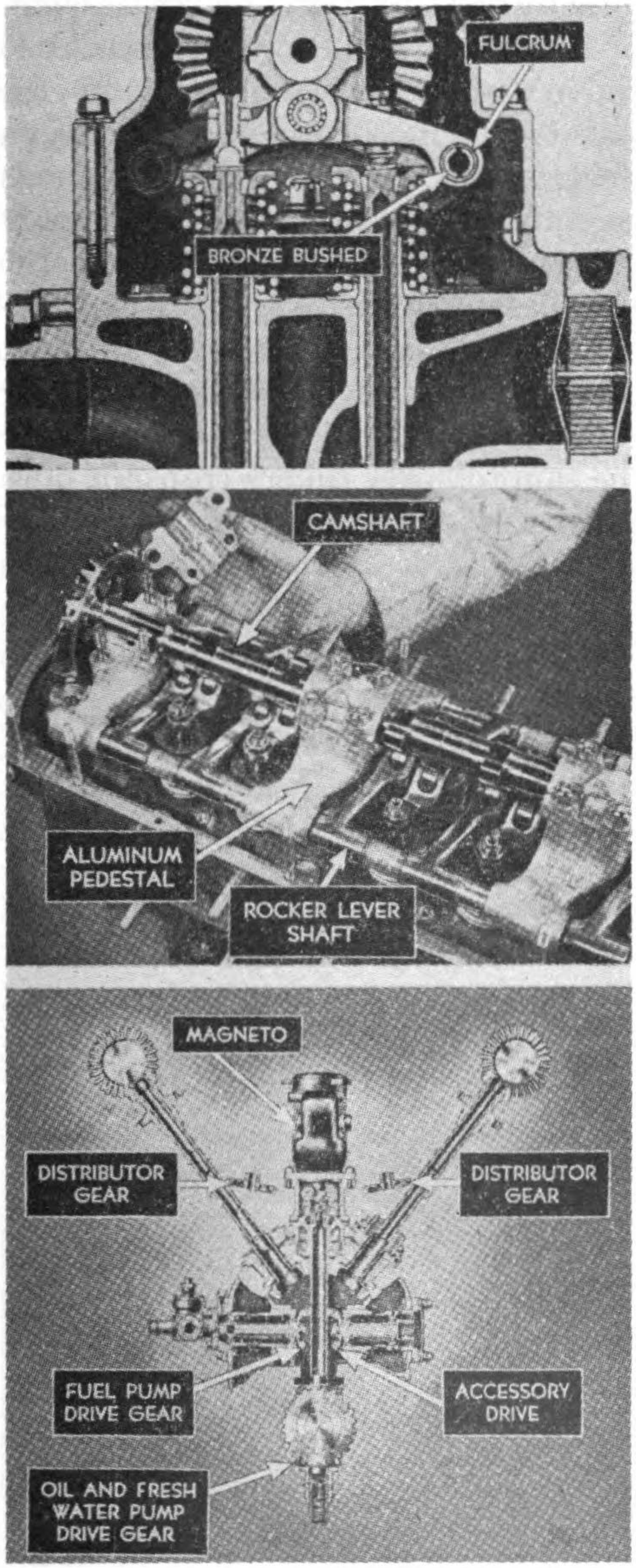


Figure 6—19.—Operating mechanisms of a V-type gasoline engine (Packard).

little apparent difference between the assemblies shown and those of Diesel engines. However, a closer look reveals that the valve rocker levers (arms) of the Packard engine illustrated in figure 6–19 are of the end-fulcrum type. In other words, the levers in this gasoline engine pivot at the ends instead of at the center as was true in the case of the rocker arms shown in connection with the discussion of Diesel engines. The valve ends of the rocker levers are fitted with ball-and-socket joints which ensure contact between the lever and the valve stem end. The rocker levers are actuated by the camshaft; and the lobes and the cam follower rollers transmit power without the aid of push rods. Note that the cam follower rollers, part of the rocker lever assemblies, are located near the center, rather than the end, of the lever.

The power to operate the valve-actuating mechanism and some of the engine accessories is supplied by a gear-type mechanism. The mechanism consists principally of bevel-type gears and shafts. A general view of the mechanism is shown in the lower illustration of figure 6–19. Note how this gear drive differs from the one for the V-type Diesel engine discussed earlier. (See figs. 6–6, 6–7, and 6–8.)

The drive mechanism is located on the supercharger end—the end opposite the power take-off—of the engine.

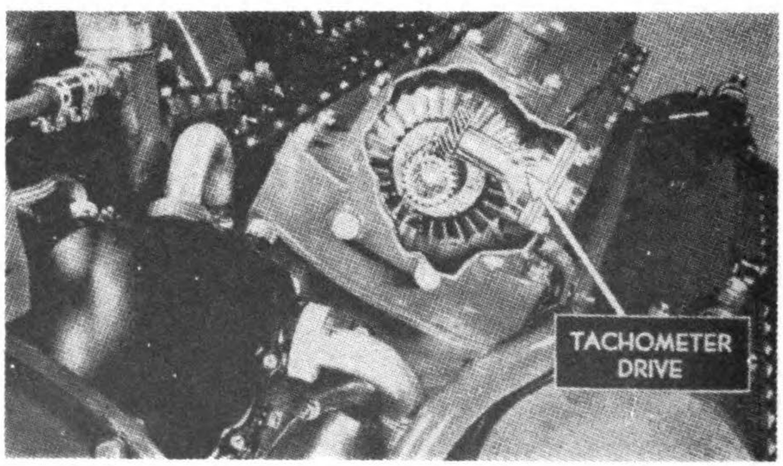


Figure 6–20.—Tachometer drive (Packard).

The drive supplies power to the camshafts, the magneto, the distributors, the fuel pump, the oil and fresh water pumps, and other accessories. Most of these receive power through a combination of gears and shafts. However, the magneto is driven through a synthetic rubber coupling which receives power from the camshaft drive center gear. The accessory drive, shown opposite the fuel pump drive gear and provided for optional equipment, is not furnished on all engines. The tachometer drive is driven from the camshaft by means of a worm gear and adapter bolted to the camshaft flange. (See fig. 6–20.)

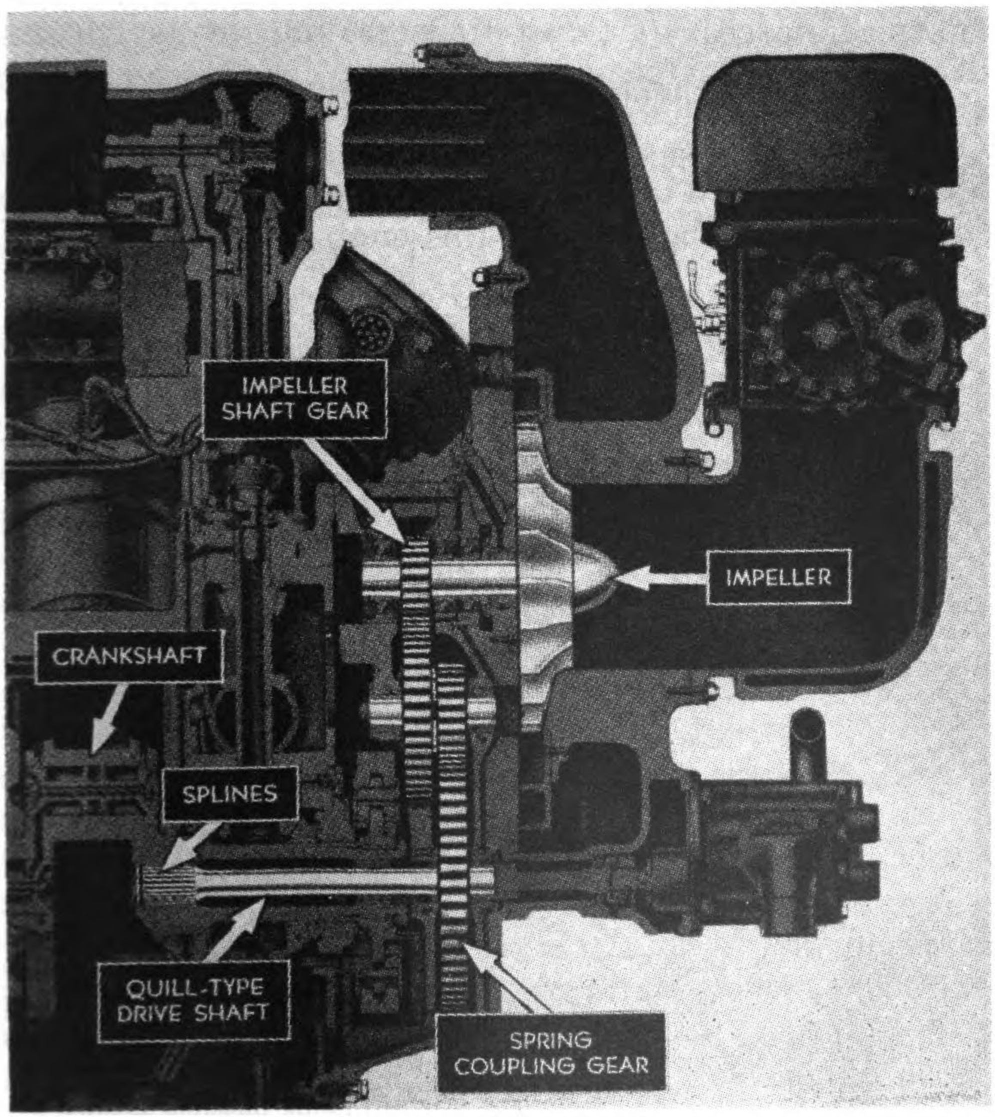


Figure 6–21.—Supercharger drive mechanism (Packard).

The supercharger or blower drives of the Packard engines used as examples in this section differ from the blower drive of the 4-stroke cycle Diesel engine discussed earlier. Instead of being driven by exhaust gases, the superchargers on these Packard engines receive power from the crankshaft, through a gear train. (See fig. 6–21.)

Located on the same end of the engine as the timing and accessory drive, the supercharger receives power from the crankshaft, through a quill-type drive shaft which is splined into the hollow end of the crankshaft. The opposite end of the drive shaft drives a spring (flexible) coupling gear, which, in turn, drives the impeller through intermediate gears.

Operating Mechanisms of an In-Line Gasoline Engine

The mechanisms shown in figure 6–22 are those of the Chrysler M8, an 8-cylinder, 4-stroke cycle, in-line gasoline engine. The mechanisms for this engine differ somewhat

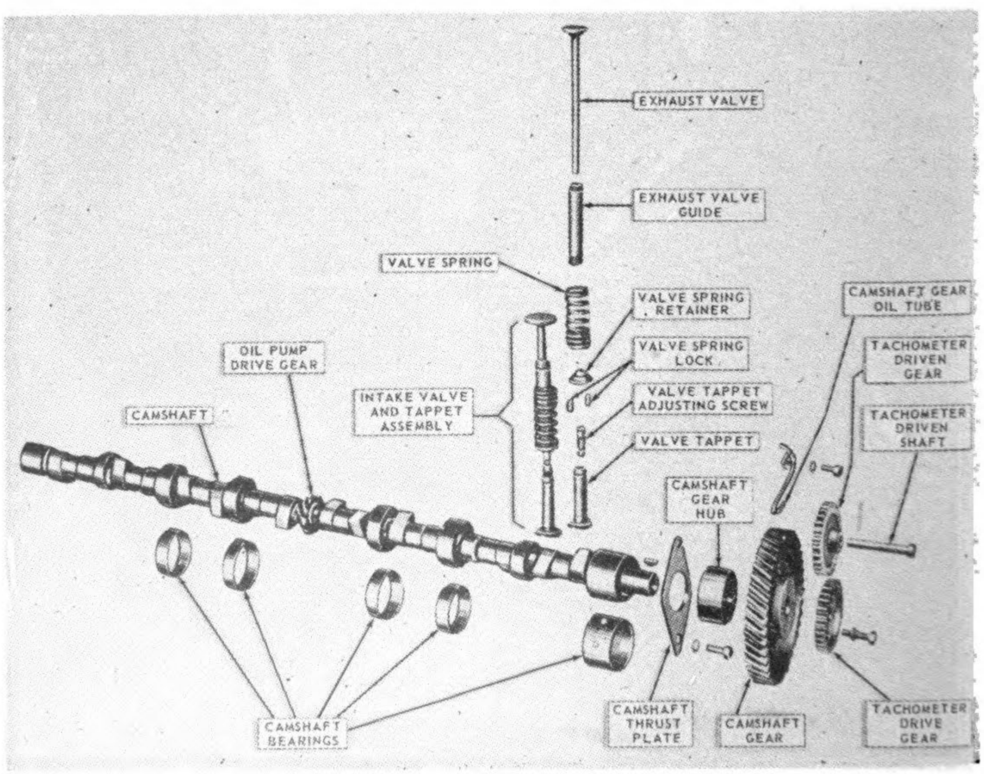


Figure 6–22.—Operating mechanisms of an in-line gasoline engine (Chrysler M8).

from those of the V-type engine just described. Size of engine and cylinder arrangement account for some of these differences. Considerable difference also exists between the operating mechanisms of the M8 and the 6-cylinder 2-stroke cycle Diesel engine discussed earlier in this chapter. (See figs. 6–1, 6–2, 6–3, and 6–4.)

The operating mechanisms of the M8 are driven by the crankshaft gear, which meshes with the camshaft gear. This gear, in turn, transmits power, through shafts and gears, for the operation of accessories and the valves.

The fuel pump is operated by a lobe on the camshaft, through a rocker arm; the drive gears of the water pump are driven by the camshaft gear; and the oil pump is driven by a spiral gear on the camshaft. The gear which supplies power to the oil pump also provides power for the distributor. The driven gear of the tachometer receives power from the tachometer drive gear, which is bolted to the camshaft gear.

The engine valves are operated by tappet assemblies, which are actuated by the cam lobes. Note the absence of rocker arms and push rods in the actuating gear. Also note the differences between the cam followers in this engine and those already discussed. In this case, the cam follower of the tappet assembly is of the flat or mushroom type rather than of the roller type shown in earlier examples.

SUMMARY

The operating mechanisms of an engine are those assemblies which transmit power for the operation of engine accessories and certain engine parts. The importance of these power-transmitting devices to efficient engine operation is evident if one considers the functions of the components to which power is transmitted. The principal parts operated are the valves which control the flow of fuel, intake air, exhaust gases, and starting air (when applicable), in the engine cylinders. The engine accessories driven are those which circulate the cooling water

and lubricating oil, supply air for scavenging and supercharging, and control engine speed.

The mechanisms which transmit the power for the operation of these engine parts and accessories may be classified as drive and actuating mechanisms. Drive mechanisms, as defined in this chapter, are those assemblies which use rotary motion in the transmission of power. The rotary motion of the crankshaft is transferred to the driven part of a chain assembly, a gear train, belts, or a combination chain-and-gear assembly. Some engines have only one drive mechanism, which is generally called the camshaft-and-accessory drive. In engines which have more than one drive, each drive is generally identified by the name of the principal part or accessory driven—such as camshaft drive or blower drive.

Actuating mechanisms are those that transform the rotary motion of a drive mechanism into reciprocating motion, which is utilized for operating engine cylinder valves. The engine camshaft is the first principal part of a valve-actuating mechanism. Rotary motion of the cams on the camshaft is changed to reciprocating motion and transmitted to the various cylinder valves (intake, exhaust, fuel injection, air starter) by means of rocker arm or tappet assemblies. Generally, these assemblies make contact with the cams by means of cam rollers; however, flat- or mushroom-type cam followers are used in some engines.

QUIZ

1. What is the name generally given to the mechanism that maintains the proper rotational relationship between the camshaft and crankshaft of an engine?
2. Name three types of mechanisms which are used to transmit power for the operation of engine parts and accessories.
3. The drive mechanism of a GM 6–71 is of what type?
4. The drive mechanism of a GM 6–71 supplies power for the operation of what two groups of parts?
5. Is there a gear reduction between the crankshaft gear and camshaft gear of the GM 6–71 drive mechanism?
6. How many cams are provided on the camshaft to serve each cylinder of a GM 6–71?
7. What is the purpose of the balance shaft in the GM 6–71 valve-actuating mechanism?
8. Trace the path of power in a GM 6–71 from the blower drive gear to the water pump, by listing the principal parts through which power flows.
9. What is the purpose of the inner rocker arm in the valve-actuating mechanism for one cylinder of a GM 6–71?
10. In a GM 6–71, how is power transmitted from the camshaft lobes to the rocker arms?
11. The mechanism which drives the camshafts of a GM 16–278A also supplies power to what engine accessories?
12. How does the GM 16–278A differ from the GM 6–71 in the manner in which power is transmitted between the cam lobes and rocker arms?
13. In the valve-actuating mechanism of a GM 16–278A, what part permits a single rocker arm to operate two exhaust valves at the same time?
14. What is the function of the valve bridge spring in the valve-actuating mechanism of a GM 16–278A?
15. Is the drive gear of the GM 16–278A accessory drive mechanism attached directly to the crankshaft or driven by the crankshaft through an intermediate shaft?
16. Identify by name and type the separate drive mechanisms of an FM 38D opposed-piston engine.
17. To which of the following—exhaust valves, accessories, fuel injection pumps—does the camshaft drive of an FM 38D transmit power?
18. From which crankshaft does the camshaft drive of an FM 38D receive power?

19. In the valve-actuating gear of an FM 38D, what performs a function similar to that of the rocker arms in the GM 6–71 and GM 16–278A?
20. From which crankshaft do most of the accessories of an FM 38D receive power?
21. What is the purpose of the elongated holes in the camshaft sprocket of the GSB–8 drive mechanism?
22. Between what two components of the drive mechanism does the gear reduction necessary to reduce camshaft speed in a GSB–8 take place?
23. Identify three camshafts of the GSB–8 and list the principal engine system(s) to which each is related.
24. Why does each cam of the GSB–8 engine camshaft have two surfaces with which each cam roller can make contact?
25. In the valve-actuating mechanism of a GSB–8, what part serves the same purpose as the valve bridge of the GM 16–278A valve-actuating mechanism?
26. With respect to pivot point, what is the difference between the rocker arms of Packard marine gasoline engines and other engines discussed in this chapter?
27. What is the difference between the supercharger drives in the two supercharged 4-stroke cycle engines considered in this chapter?
28. Name three types of gears which may be found in drive mechanisms.
29. What type of cam followers are used in the majority of the engines discussed in this chapter?

CHAPTER 7

ENGINE FUELS AND FUEL SYSTEMS

We have learned that both air and fuel must be supplied to the cylinders at the proper time and in the proper quantity, if an engine is to operate efficiently. We have also noted that heat must be applied to the air-fuel mixture at the proper time, with respect to the piston position, during the cycle.

The steps and mechanisms involved in the delivery of air to the combustion spaces of an engine at the proper time have been discussed in chapter 5 of this course. The parts of an engine used to supply the heat energy required to cause combustion are considered in the next chapter of this course. This chapter deals primarily with fuel and the system which delivers fuel to the combustion spaces of an engine. Before discussing fuels and fuel systems, however, it will be helpful if we first give consideration to the factors related to combustion and fuels.

COMBUSTION AND FUELS

Diesel and gasoline engines are similar mechanically. The operation of each type of engine depends upon air, fuel, compression, and heat. Operating cycles for both Diesel and gasoline engines are similar in that the events take place in the same order. The principal moving parts in each type of engine transform reciprocating motion into rotary motion. Engines of both types extract energy from the burning of an air-fuel mixture inside a cylinder. Even though Diesel and gasoline engines are similar in many respects, several differences exist. These differences

are related to combustion and involve principally the fuel and heat necessary for combustion. (Since the heat necessary for combustion is more commonly referred to as ignition, this latter term is used in the subsequent material.)

A Comparison of Factors Related to Combustion in Diesel and Gasoline Engines

Diesel and gasoline engines differ principally in the method of admitting fuel to the cylinders and in the manner of igniting the combustible mixture in the cylinders. Some of the factors related to the main differences between these two engines are considered here.

FUEL AND AIR ADMISSION, MIXING AND IGNITION.—In the Diesel engine, fuel and air are admitted separately into the cylinders, where mixing takes place. In gasoline engines, fuel and air are mixed in the carburetor before being admitted to the cylinders. The pistons of a gasoline engine compress a fuel-air mixture, which is ignited by an electric spark. On the other hand, only air is compressed in a Diesel engine and fuel is injected into the cylinder and mixed with the compressed air. The heat caused by compression of air is solely responsible for ignition in a Diesel engine. Fuel injection starts during the operating cycle of a Diesel engine at about the same time that spark ignition occurs in the cycle of a gasoline engine.

PRESSURE AND HEAT IN THE CYLINDER.—The pressure developed during the compression event is much greater in a Diesel engine than in a gasoline engine because of the higher compression ratio in the Diesel engine. There is a temperature increase of about 2° F for each pound of pressure exerted on the air. Therefore, the temperature in the cylinder of the Diesel engine will be considerably greater than the temperature in the cylinder of the gasoline engine. The heat in the cylinder of a Diesel engine is sufficient to cause combustion almost as soon as the fuel is injected. In a gasoline engine, energy from an external

source is necessary for ignition since the heat due to compression is not enough to cause self-ignition of the air-fuel mixture.

COMPRESSION AND POWER OUTPUT.—If an engine is to develop the highest power output possible from the fuel-air mixture in the cylinders, the mixture must be compressed as much as practicable. The higher the pressure in a cylinder after the compression event, the greater the power output. The pressure resulting from compression is indicated by compression ratio. Even though compression ratio is an indication of pressure, it should be remembered that the compression ratio of an engine is based upon the mixture and minimum volumes with the cylinder. (See *Fireman,* NavPers 10520–A and chapter 2 of this training course.)

In gasoline engines, where fuel and air are compressed as a mixture, the highest practical pressure in the cylinders is determined by the characteristics of the fuel. Early gasoline engines were designed with relatively low compression ratios because the available fuel produced a combustion knock when subjected to high compression. Since greater power was a desired feature of an engine and since greater power and higher compression are directly related, the production of a gasoline which would burn satisfactorily under high cylinder pressure was essential. Through the use of additives and by improved refining methods, gasolines were produced that would burn satisfactorily under high compression. The production of improved gasolines has led to the design and development of engines which have compression ratios that are about twice as high as those of early gasoline engines; thus, the term "high compression" applies to many modern gasoline engines.

In Diesel engines, where air alone is compressed, the principal limitation on compression is the ability of the engine to withstand the heavy strains produced by high compression pressures. Diesel engines develop a "knock" during normal operation. This knock is not caused by

high compression ratio, but instead is believed to be caused by the rapid burning of the fuel which accumulates between the time injection starts and ignition takes place. The characteristics of fuel which lead to knocking are taken into consideration by designers in the development of engines. The characteristics of fuels and their relationship to engine operation are considered in the next section of this chapter.

TIME OF IGNITION.—The time at which the air-fuel mixture in the cylinder of an engine should be ignited depends upon such factors as the speed of the engine, the type of fuel used, and the compression ratio. Both Diesel and gasoline engines are designed so that ignition occurs near, but before, the end of the compression event. Provision is made in most Diesel and gasoline engines for advancing or retarding the point at which ignition takes place. The ignition point is advanced with an increase in engine speed and retarded as speed is reduced. The methods used to cause ignition to occur at the proper point in the cycles of operation differ in the two types of engines. (More information on this subject will be given later in this chapter and in the chapters which follow.)

Maximum power is developed in the cylinder of a GASOLINE ENGINE when the maximum combustion pressure is reached. Maximum pressure occurs during the power event, when the piston is a few degrees past TDC. During combustion in the cylinder of a gasoline engine, the air-fuel mixture burns very rapidly; yet, the process is slow enough to make ignition necessary before the end of the compression event. Ignition has to take place before TDC is reached, in order for combustion to be completed, or nearly so, by the time the piston reaches the maximum power position. The time required for combustion to take place (for a given compression ratio and fuel) does not change with engine speed. However, as engine speed increases, a complete cycle of operation takes place within a shorter period of time. As engine speed increases and cycle time decreases, therefore, combustion must begin

earlier if the process is to be completed at the same point in the cycle as it was before the engine speed was increased. In order for combustion to start earlier, a means of varying the time of ignition throughout the speed range of the engine is required.

If ignition takes place too early in the cycle, combustion will be completed before the piston reaches TDC at the end of the compression event. When combustion is completed before the piston reaches TDC, maximum pressure occurs before the piston is in position to deliver power. When this situation occurs, the momentum of the flywheel and related rotating engine parts must overcome the pressure of combustion to get the piston past TDC. The opposed forces result in considerable power loss. The situation just described is not likely to occur in the modern engine. However, the point is emphasized here to stress the fact that ignition must be so timed that the pressure developed during combustion reaches a maximum shortly after the piston passes TDC and is in a position to deliver power to the crankshaft.

When ignition occurs too late in the cycle, combustion will be completed after the piston has passed the maximum power position. The pressure developed is less than maximum when ignition occurs late, because combustion will then have taken place in a larger space.

As in gasoline engines, the time of ignition in DIESEL ENGINES must be such that maximum pressure is produced when the piston is in the proper position. However, due to differences between the Otto and Diesel cycles, factors related to ignition in the two cycles differ to a degree.

The time of ignition in a Diesel engine is governed by the time of fuel injection. Regardless of the amount of fuel injected, ignition starts shortly after the fuel reaches the hot compressed air. Pressure begins to rise as the first particles of fuel entering the cylinder begin to burn. The rate and amount of fuel injected determine the maximum pressure obtained and the speed of the engine. As

combustion progresses, more fuel is injected. Because of the fuel added during combustion, the pressure on the piston, as it moves toward BDC during the power event, is almost constant. Since the amount of fuel injected determines engine speed, the longer the period of injection the greater the engine speed. At high engine speeds, combustion in a Diesel engine tends to approach the constant-volume process of the gasoline engine.

Turbulence and Combustion in Diesel Engines

In both gasoline and Diesel engines, it is essential that the fuel and air be properly mixed if efficient combustion is to be obtained. In a gasoline engine, mixing takes place outside of the cylinder (in the carburetor) and the proper mixture is forced into the cylinder, to be compressed. In the Diesel engine, however, fuel in the form of small particles is forced into the cylinder after the air has been compressed. If each particle of fuel is to be surrounded by air sufficient to effect complete combustion (that is, if proper air-fuel mixture is to be obtained), it is essential that the air in the combustion space be in motion. This air motion is called turbulence.

Various means are used to create the turbulence required for efficient combustion in Diesel engines. Design of engine equipment and parts and, in some cases, a process called precombustion enter into the creation of proper turbulence within the cylinder of an engine.

METHODS OF CREATING TURBULENCE.—Turbulence is created, in part, by fuel injection. Most of the turbulence, however, results from special shapes in the combustion chamber.

Distribution of fuel is accomplished by the use of injection nozzles which atomize the fuel and direct it to the desired portions of the combustion space. FUEL INJECTION creates some turbulence, but not enough for efficient combustion. Additional motion of the air is created by design features of the combustion space.

In 2-stroke cycle engines, scavenging-air PORTS are so

designed and located that the intake air is admitted to the cylinder with a whirling or circular movement. The movement of the air continues through the compression event and aids in mixing the air and fuel when injection occurs.

While the ports in 2-stroke cycle engines and fuel injection aid in creating air movement, additional turbulence is created in most engines by special shapes in the COMBUSTION SPACE. These may include the piston crown and that portion of the cylinder head which forms part of the main combustion space. In some cases auxiliary combustion chambers are provided as part of the combustion space, to aid in mixing the fuel and air.

Even though there are many types of combustion chambers, all are designed to produce one effect—to bring sufficient air in contact with the injected fuel particles to provide complete combustion at a constant rate. Combustion chambers may be broadly classified under four types: open, precombustion, turbulence, and divided chambers. The last three terms are more commonly used to identify auxiliary combustion chambers. Since they are associated with the process called precombustion, the chambers and their functions are covered in a subsequent section of this chapter, under "Precombustion and Turbulence."

The open combustion chamber is the simplest in form. The fuel is injected directly into the top of the combustion space. The piston crown and, in some cases, the cylinder head are shaped to provide a swirling motion of the air as the piston moves toward TDC during the compression event. There are no special chambers to aid in creating turbulence. Most of the engines used as examples in the preceding chapters of this training course have open combustion chambers. Chambers of this type require higher injection pressures and a greater degree of atomization than other types to obtain the same degree of turbulence and mixing.

PRECOMBUSTION AND TURBULENCE.—Some Diesel engines are provided with an auxiliary space or chamber at or near the top of each main combustion space. These chambers are designed to receive all or part of the injected fuel and condition it for final combustion in the main combustion chamber of the cylinder. This conditioning, called precombustion, involves a partial burning of the fuel before it enters the main combustion space. Precombustion aids in creating the turbulence necessary for the proper mixing of the fuel and air. Because of differences in designs, the manner in which precombustion aids in creating turbulence differs from one type of auxiliary combustion chamber to another. For this reason, three types of auxiliary chambers are considered here, under the names by which they are sometimes identified—precombustion and turbulence chambers, and air or energy cells.

One type of engine in which PRECOMBUSTION CHAMBERS are included as part of the combustion spaces is the Packard Diesel, Series 142. The part that the precombustion chamber plays in creating turbulence can be determined by referring to figure 7–1.

The precombustion chamber, spherical in shape, is located in the cylinder head directly over the center of the piston crown. The precombustion chamber is connected to the main combustion space of the cylinder by a multiple orifice called the burner. During the compression event, a relatively small volume of compression-heated air is forced through the burner into the precombustion chamber. Heat stored by the burner increases the temperature of the compressed air and facilitates initial ignition.

Fuel is atomized and sprayed into the hot air in the precombustion chamber (A) and combustion starts (B). Only a small part of the fuel is burned in the precombustion chamber, because of the limited amount of oxygen. The fuel which does burn in the chamber creates sufficient heat and pressure to force the fuel, as injection continues, into the cylinder at great velocity (C).

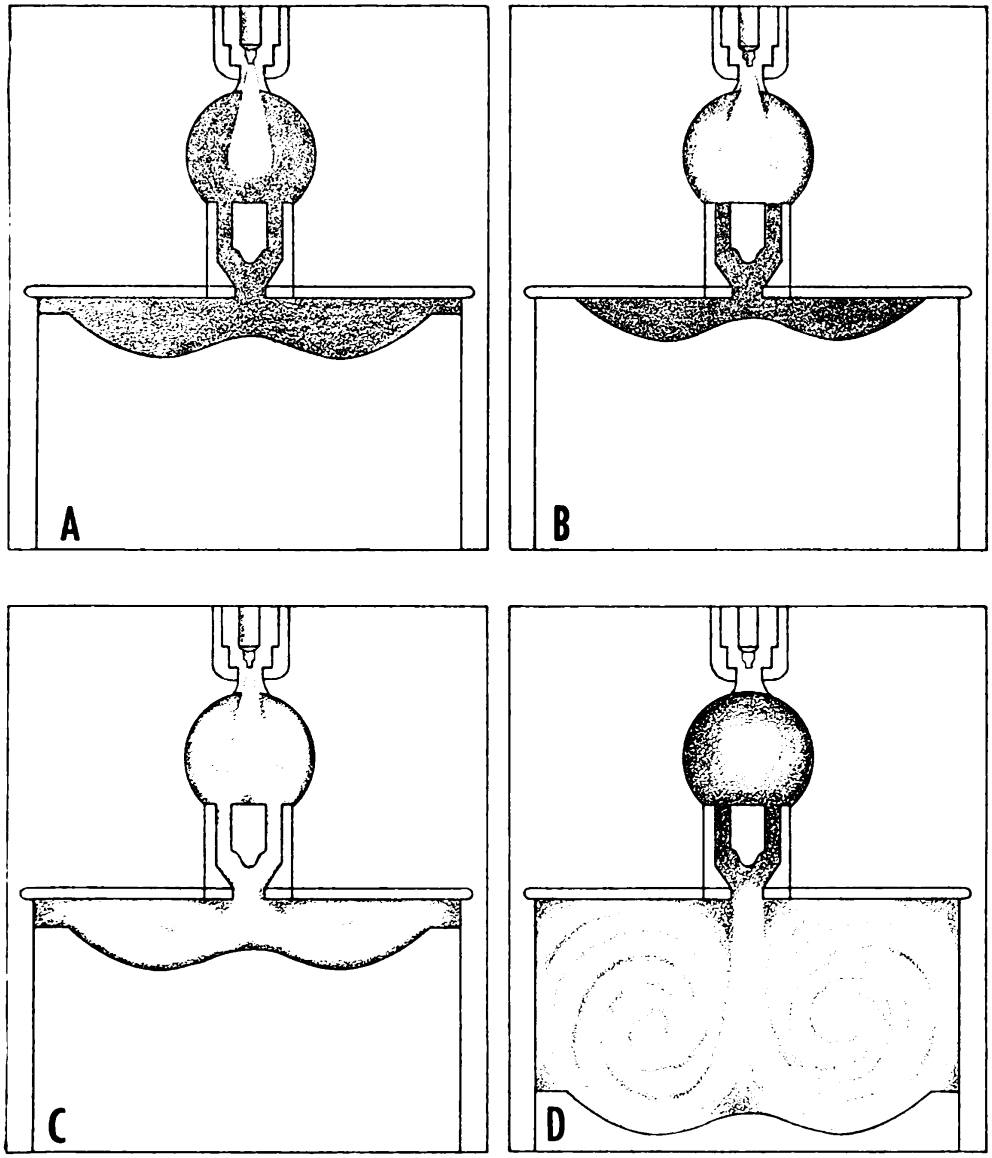


Figure 7—1.—Precombustion chamber (Packard Diesel, Series 142).

The velocity of the fuel entering the main combustion space and the shape of the piston crown aid in creating the necessary turbulence within the cylinder (D).

Engines designed with precombustion chambers do not require fuel injection pressures as great as those necessary in engines equipped with chambers of the open type. Also, the spray of injected fuel can be coarser, since the precombustion chamber functions to atomize the fuel further before it enters the cylinder.

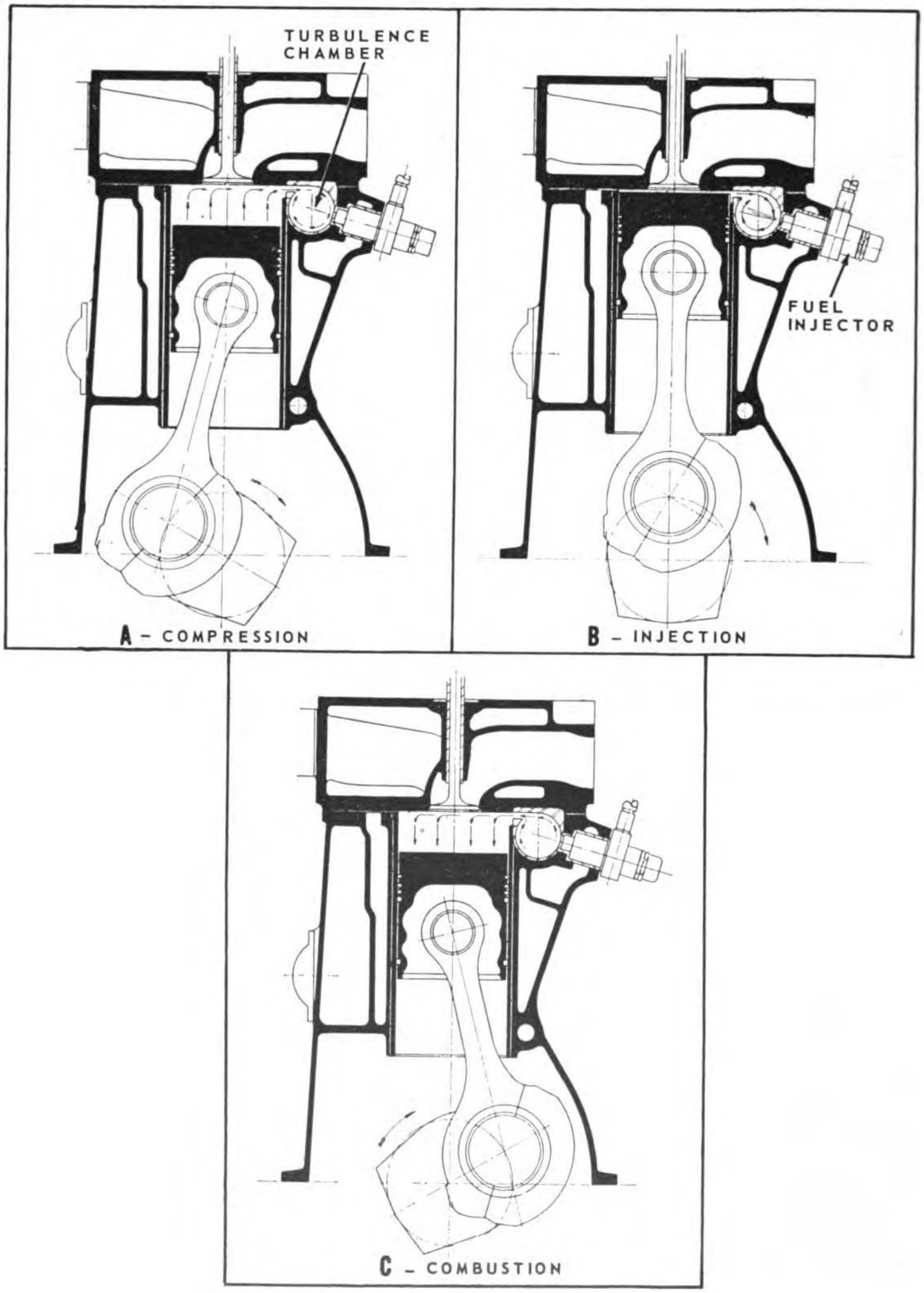


Figure 7-2.—Turbulence chamber (Hercules, DWXD).

Some engines are equipped with auxiliary combustion chambers which differ from precombustion chambers principally in that nearly all of the air supplied to the cylinder during the intake event is forced into the auxiliary chamber during the compression event. Auxiliary chambers in which this occurs are sometimes referred to as TURBULENCE CHAMBERS. There are several variations of turbulence chambers, one of which is illustrated in figure 7–2.

Note how turbulence, indicated by the arrows, is created in the auxiliary chamber as compression (A), injection (B), and combustion (C) take place. In engines utilizing turbulence chambers, there is very little clearance between the top of the piston and the head when the piston reaches TDC. (See B, fig. 7–2.) For this reason, a high percentage of the air in the cylinder is forced into the turbulence chamber during the compression event. The shape of the chamber (usually spherical) and the size of the opening through which the air must pass aid in creating turbulence. The opening to the turbulence chamber becomes smaller as the piston reaches TDC, thereby increasing the velocity of the air. Velocity plus deflection of the air as it enters the auxiliary chamber creates considerable turbulence. Fuel injection (B) is timed to occur when the turbulence in the chamber is the greatest. This ensures a thorough mixing of the air and fuel. The greater part of combustion takes place within the turbulence chamber and is completed as the burning gases expand and force the piston down in the power event.

In some high-speed Diesel engines, turbulence is created by an auxiliary chamber referred to as an ENERGY (AIR) CELL. Energy cells differ in design and location. In some cases, the cells are a part of the piston crowns. In other engines, the cells are located in the cylinder head(s). One type of energy cell which is located in the cylinder head is a divided chamber, which is, in effect, a combination precombustion chamber and turbulence

chamber. The Lanova combustion chamber with energy cell is of the divided chamber type. Cross-sectional top and side views of a divided auxiliary combustion chamber are shown in figure 7–3.

The divided auxiliary combustion chamber illustrated consists of a figure 8-shaped main combustion chamber (turbulence chamber) and an energy cell (precombustion chamber) which includes two air chambers. The main

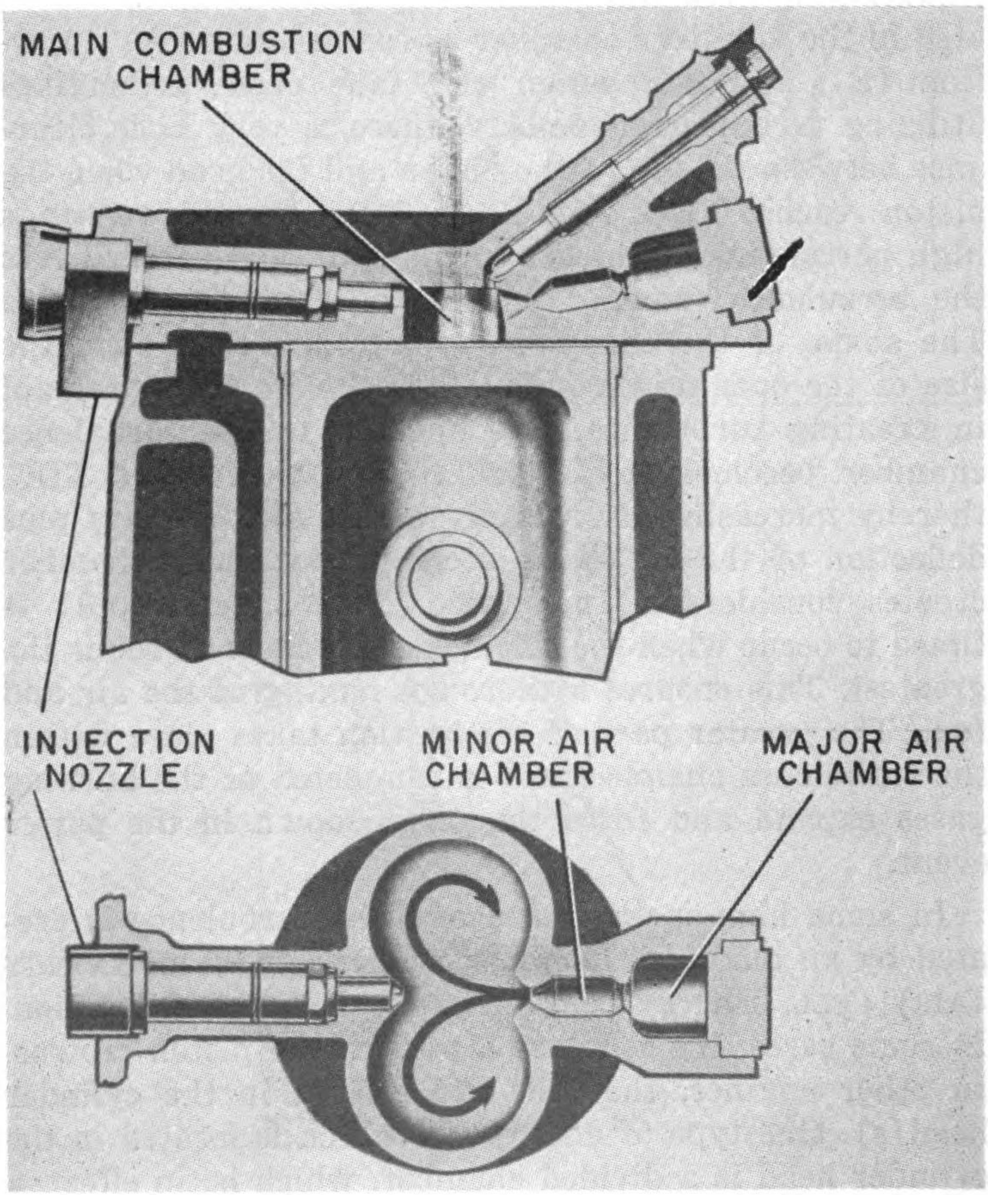


Figure 7–3.—Divided combustion chamber.

combustion chamber is located centrally, over the piston, and provides a housing for the engine valves. The energy cell is located to the side, directly opposite the fuel injection nozzle. The inner, or minor, air chamber of the energy cell is connected to the main combustion chamber and to the larger, or major, chamber of the cell by funnel-shaped passages.

The air charge is forced into the main combustion chamber during the compression event with a relatively small amount entering the energy cell at high velocity. Most of the fuel remains in the minor air chamber. However, enough fuel enters the major air chamber (where a sufficient quantity of compression-heated air is available) to create a spontaneous combustion of the mixture of fuel and air. Combustion in the major air chamber produces an extremely rapid rise in pressure, which forces the fuel in the minor air cell back into the main combustion chamber. Because of the shape of the main combustion chamber, an exceedingly high rate of turbulence is created; thus causing a highly efficient mixing of unburned fuel with the air in the main combustion chamber. Combustion in the main chamber is relatively smooth and continuous compared to the spontaneous nature of the combustion in the energy cell. The restrictions in the connecting passages of the air chambers control the flow of fuel back into the main chamber so that combustion is prolonged, rather than sudden. Thus, the rate of pressure rise on the piston is gradual, resulting in smooth engine operation.

The divided type combustion chamber is similar, in some respects, to other types of chambers. A divided combustion chamber is similar to the open combustion chamber in that the main volume of air remains in the main combustion chamber, and principal combustion takes place there. Both the divided chamber and the turbulence type chamber depend on a high degree of turbulence to ensure thorough mixing and distribution of the fuel and air. However, turbulence in a divided combustion chamber

is dependent upon thermal expansion caused by combustion in the energy cell and not on engine speed as in the case of other types of auxiliary combustion chambers.

Engine Fuels

Except in cases of emergency, the fuels burned in the internal combustion engines used by the Navy meet the specifications prescribed by the Bureau of Ships. Thus, the problem of selecting a fuel which has the required properties is not your responsibility. Your primary responsibility is to follow the rules and regulations dealing with the proper use of fuels. Strict adherence to prescribed safety precautions is required. Also, every possible precaution must be taken to keep fuel as free from impurities as possible.

Fuels are generally delivered clean and free from impurities. However, the transfer and handling of fuel increase the danger of fuel becoming contaminated with foreign material which interferes with engine performance. Foreign substances such as sediment and water cause wear, gumming and corrosion in the fuel system. Foreign material in fuel also causes an engine to operate erratically, with a power loss. For these reasons, the necessity for periodic inspection, cleaning and maintenance of fuel handling and filtering equipment must be kept constantly in mind.

Even though proper handling and use is your prime responsibility with respect to fuel, a knowledge of fuels and their characteristics will make problems encountered in engine operation and maintenance more readily understood.

GASOLINE.—A knowledge of the properties of gasoline will help you understand why you must keep engine operation within the limits prescribed in operating instructions. For use as engine fuel, gasoline must meet rigid requirements. It must vaporize readily and must be capable of producing power without fuel knock. Gasoline must also be free of impurities which would interfere with the

operation of the engine or the units of the fuel system. The ability of a liquid to change to vapor is referred to as the VOLATILITY of the liquid. All liquids tend to vaporize at atmospheric temperature, but their rates of vaporization vary. The rate of vaporization increases as the temperature increases and as the pressure decreases, temperature being the more important factor. In general, a highly volatile fuel will vaporize at atmospheric temperatures whereas high temperatures are required to vaporize a fuel of low volatility.

The volatility of gasoline affects engine starting, length of warm-up period, and engine performance. The manner in which engine operation is influenced by the volatility of the gasoline may be more fully understood by considering volatility from the standpoint of how it influences starting and fuel distribution and how it may be the cause of vapor lock and crankcase dilution.

Gasoline must be in the form of vapor in order to properly combine with oxygen during combustion. Thus, a gasoline with high volatility is desirable for engine starting since it is volatility which determines how much fuel will be vaporized in the fuel-air mixture. Generally, the proper fuel-air mixture consists of about 15 parts of air to 1 part of fuel, by weight. Even with this ratio, some of the vaporized fuel condenses and collects in the manifold when a "cold" engine is being started. Thus, more fuel must be added to make enough fuel available for starting and for operation until the engine reaches operating temperatures.

Proper distribution of fuel to the cylinders of a gasoline engine depends, in part, upon the fuel being completely vaporized and mixed with air within the carburetor. Incomplete vaporization will result in an unequal distribution of the fuel-air mixture to the cylinders. When the fuel is not completely vaporized, engine operation will be "rough" and power output will be decreased. A fully vaporized fuel mixture entering the combustion

chambers is also essential for rapid and smooth acceleration of the engine.

Even though high volatility is a desirable characteristic of gasoline, volatility should not be so high that excessive vapors form within the fuel system.

When excessive vapors form, the condition is called vapor lock. Vapor lock may develop if the liquid fuel evaporates before it reaches the carburetor. The fact that gasoline tends to vaporize at normal atmospheric temperatures increases the possibility of vapor lock. When fuel vaporizes before reaching the carburetor, bubbles may form in the fuel line, blocking or restricting the flow of fuel. If the fuel pump delivers a mixture of liquid fuel and fuel vapor to the carburetor, the amount of available fuel is reduced considerably and an improper fuel-air mixture results. This reduction in the fuel supply may be sufficient to prevent the engine from operating at full power or it may cause the engine to stop.

Another difficulty which is related to volatility is crankcase dilution. Fuel may not be completely vaporized when it enters the cylinders, or fuel vapor may condense after it enters the intake manifold or cylinders. These conditions are more common to cold-weather starts, when fuel vaporizes less readily, when vaporized fuel has a greater tendency to condense, or when choking or priming may be excessive. Any unvaporized fuel which accumulates in the cylinders will leak past the pistons and rings into the engine lubricating oil during the warm-up period. The liquid fuel entering the crankcase dilutes the oil and reduces its lubricating qualities.

The ability of a fuel to burn in the cylinder of an engine without producing an undesirable knock, or "ping," is referred to as the fuel's ANTIKNOCK QUALITY. To understand the value of the antiknock characteristic of fuel, it is necessary to be familiar with the combustion process as it occurs in the cylinder of a gasoline engine.

Even though the burning of the fuel-air mixture in the cylinder of a gasoline engine is commonly thought of as

one rapid event, the process, during normal operation, can be divided into three "phases of combustion." As soon as the spark jumps the gap between the spark plug electrodes, a small ball of blue flame develops in the gap. The development of this flame is considered the first phase of combustion. With respect to the combustion process as a whole, the enlargement of the ball of flame is relatively slow and during its growth in the first phase, the pressure created by heat is negligible.

The second phase of combustion consists principally of the enlargement of the ball of flame. During this phase the ball of flame spreads out, sending flames into some of the mixture in the combustion space. The expansion of the flame causes only enough heat to make a slight rise in temperature and pressure throughout the fuel-air mixture.

The third and longest phase is the effective burning period of combustion. The mixture burns with a "front" (sometimes called a wall or boundary) existing between the burning mixture and the unburned mixture. The front of flame moves rapidly across the combustion space, as the burning mixture generates extreme heat with an accompanying rise in pressure.

Even though normal combustion is rapid, it is by no means an instantaneous explosion. The burning process is progressive, with the mixture burning evenly and smoothly. The flame advances through the mixture at a gradually increasing rate until, in the final phase, the rate of advance is roughly four times greater than that in the early phases of combustion. The burning then slows down, as the process nears completion.

If combustion is to be normal, the correct fuel must be used and the engine must be in proper operating condition. If either the fuel or the engine's operating condition is unsatisfactory, a portion of the fuel charge in a cylinder may explode instantaneously, instead of burning gradually. Loss of power and undesirable combustion noises are symptoms of such abnormal burning or uncon-

trolled combustion. The noises, or knocks, which result from abnormal combustion are generally referred to as fuel knocks, not engine knocks.

A fuel knock caused by abnormal or uncontrolled combustion during the final phase is generally called "detonation." Detonation occurs when the temperature and pressure of the unburned mixture in the combustion space become greater than the temperature and pressure characteristic of normal combustion. The result is an instantaneous, rather than gradual, burning of the remaining mixture. Detonation is accompanied by an abrupt pressure rise and extremely rapid and violent pressure fluctuations. The engine is unable to convert into useful power the energy which is released so suddenly by the instantaneous explosion. The recurring shock pressures are transmitted to the piston and to other engine parts; and fatigue stresses are created which quickly lead to failure of the parts. Detonation also causes a rapid rise in cylinder temperatures, thus aggravating the conditions that cause it. The temperatures caused by detonation are sufficiently high to seriously damage engine parts related to the combustion space.

Anything which excessively increases the temperature or the pressure of the unburned mixture in a cylinder contributes to detonation. For example, too high a compression ratio causes detonation because of the excessive heat generated by the excessive compression. Other factors which may lead to detonation are the cylinder temperatures, the amount of the fuel-air mixture, the temperature of the fuel-air mixture, the fuel-air ratio, the intake manifold pressure, the position of the spark plug or plugs, and the shape of the combustion chamber. In addition to these, another important factor which affects detonation is the antiknock quality of the fuel.

The antiknock characteristic of a gasoline is measured by its "octane value." This value is expressed in terms of an octane number. The octane number for a gasoline

is determined by comparing the gasoline's performance with that of a fuel for which the octane value is known.

Two of the hydrocarbons in gasoline are iso-octane and normal heptane. The first has high antiknock qualities while those of the latter are low. For purposes of comparison, pure iso-octane is considered to have an octane value of 100 and normal heptane an octane value of zero. The performance of a gasoline of unknown octane value is compared with the performance of mixtures of normal heptane and iso-octane in a test engine, under specified test conditions. The proportions of iso-octane and normal heptane are varied until a mixture of these two hydrocarbons is found which gives the same degree of knocking in the engine as the gasoline with the unknown octane value. The fuel with the unknown octane value is then given an octane rating number which represents the percent of iso-octane in the hydrocarbon test mixture. For example, a gasoline with an 80-octane rating has knocking characteristics similar to those of a test mixture consisting of 80 percent pure iso-octane and 20 percent normal heptane.

Many of the gasoline engines used by the Navy burn what is referred to as an all-purpose fuel. Gasoline so classified is an 80-octane gasoline. Some high-speed gasoline engines are designed to operate on fuel with not less than an 87-octane rating, while others require a 100-octane fuel for normal operation. In either case, substitutes may be used without fuel-setting adjustments. However, when a fuel with a rating other than that specified for a particular engine is used, the prescribed limits on operating temperatures and pressures of the engine must not be exceeded.

With respect to octane rating, the tendency of a fuel to detonate varies in different engines and in the same engine under different operating conditions. The octane rating has nothing to do with starting qualities, potential energy, volatility, or other characteristics of a fuel. In general, the higher the octane value of a fuel, the less the

fuel will knock. However, it must be kept in mind that each engine is designed to operate within a certain octane range. Performance is improved with the use of higher octane fuel within that range if the time of ignition is adjusted accordingly. However, if an engine operates satisfactorily at the upper limit of the octane-rating range, the performance of the engine will not be improved by using a fuel with a higher octane rating.

During the refining process, "antiknock compounds" are added to a gasoline to reduce its tendency to knock. Antiknock compounds reduce the rate of burning of the fuel during the final phase of combustion. Thus, these compounds tend to prevent explosive burning or detonation.

One of the most common antiknock compounds is tetraethyl lead. Since gasoline is supplied with the proper amount of lead or other knock inhibitor added, your primary responsibility is to use the fuel for the purposes intended. Gasoline which contains antiknock compounds should be used only for engine fuel. Regulations specify that "gasoline shall not be used for cleaning purposes under any circumstances." The need for such a regulation is obvious when the fire and toxic hazards of gasoline are considered. You are well aware of the explosive properties of a mixture of gasoline vapor and air. Regular gasoline has some toxic effect on the human system; however, a gasoline with a high octane rating has a greater poisonous effect since such a gasoline has a greater lead content. The lead compound vaporizes with the gasoline and may enter the body when the vapor is inhaled, by absorption through the skin, and by mouth. Thus, for your own safety, do not breathe air contaminated with gasoline vapors and avoid contact with the liquid fuel. If any portion of your skin comes in contact with gasoline, wash the area with soap and water.

A fuel knock similar to that caused by detonation may occur in an engine when the compressed fuel-air mixture ignites before the spark plug fires. When this happens,

the accompanying noise is called a "preignition" knock. Preignition should not be confused with detonation. Remember that detonation takes place late in the burning process, well after the spark has occurred; while preignition always occurs before the normal point of ignition.

Ignition of the fuel-air mixture during the compression event, before the spark occurs, is caused by some form of "hot spot" within the cylinder. Hot spots may be caused by an overheated valve, a hot spark plug, or an incandescent piece of carbon. Also, the excessive temperatures which accompany detonation can lead to preignition. The reverse is also true, as conditions which cause preignition may lead to detonation. Nevertheless, the two are separate and distinct events. Preignition and detonation are both extremely harmful to an engine and steps should be taken to eliminate their causes.

The extensive heat generated by preignition or detonation may be great enough to melt parts or, at least, damage them seriously. In addition to overheating, other effects of preignition and detonation are broken engine parts, high fuel consumption, overloaded bearings, loss of power, and a need for overhaul at more frequent intervals.

DIESEL FUEL OIL.—The fuel used in Diesel engines has much in common with gasoline. Because of the differences in the combustion processes and in the fuel systems of Diesel and gasoline engines, however, the fuels for these engines must be refined to meet different requirements. In general, Diesel engines require a fuel which is particularly clean; otherwise, the closely fitted parts of the injection equipment will wear rapidly and the small passages which create the fuel spray within the cylinders will become clogged. In addition, the composition of Diesel fuel oil must be such that it can be injected into the cylinders in a fine mist of fog. Also, ignition qualities must be such that the fuel will ignite properly and burn rapidly when it is injected into the cylinders.

Gasoline must have a certain amount of resistance to self-ignition (spontaneous ignition) from the heat created during the compression event. However, the fuel used in Diesel engines need not have such resistance, since the fuel is not injected into the combustion space until after the compression of the intake air. Nevertheless, Diesel fuel must have the ability to ignite spontaneously soon after injection starts. The ease or rapidity with which Diesel fuel oil ignites is referred to as the IGNITION QUALITY of the fuel.

The self-ignition point of a fuel is a function of temperature, pressure, and time. In a Diesel engine which is operating properly, the intake air is compressed to a high temperature and pressure, and the injection of fuel starts a few degrees before the piston reaches TDC. The fuel is ignited by the heat of compression shortly after the fuel injection starts, and combustion continues throughout the injection period. Combustion is much slower than in a gasoline engine, and the rate of pressure rise is relatively small.

After injection, the first effect on the fuel is a partial evaporation, with a resultant chilling of the air in the immediate vicinity of each fuel particle. However, the extreme heat of compression rapidly heats the fuel particles to the self-ignition point and combustion begins. The fuel particles burn as they mix with the air, the smaller particles burning rapidly, and the larger particles taking more time to ignite because heat must be transferred into them to bring them to the self-ignition point.

There is always some delay between the time fuel is injected and the time it reaches the self-ignition point. This delay is commonly referred to as "ignition delay" or "lag." The duration of the ignition delay is dependent upon the characteristics of the fuel, the temperature and pressure of the compressed air in the combustion space, the average size of the fuel particles, and the amount of turbulence present in the space. As combustion progresses, the temperature and pressure within the space

rise; thus, the ignition delay in the case of fuel particles injected late in the combustion process is less than in the case of those injected earlier. The delay period between the start of injection and the start of self-ignition is sometimes referred to as the first phase of combustion in a Diesel engine. The second phase of combustion includes ignition of the fuel injected during the first phase, and the spread of the flame through the combustion space, as injection continues. The resulting increases in temperature and in pressure reduce the ignition lag for the fuel particles entering the combustion space during the remainder of the injection period.

Remember that only a portion of the fuel has been injected during the first and second phases. As the remainder of the fuel is injected, the final or third phase of combustion takes place. The increases in temperature and in pressure during the second phase and as the third phase progresses are sufficient to cause most of the remaining fuel particles to ignite, with practically no delay, as they come from the injection equipment. The rapid burning during the final phase of combustion causes an additional, rapid increase in pressure, which is accompanied by a distinct and audible knock. A knock so caused is characteristic of normal Diesel operation, particularly at light loads.

The knock which occurs during the normal operation of a Diesel engine should not be confused with "detonation." As was pointed out earlier in this chapter, detonation in a gasoline engine occurs during the final phase of combustion. In a gasoline engine, detonation is the instantaneous and spontaneous explosion, instead of gradual burning, of the fuel during the final phase of combustion. Detonation in a Diesel engine is also an instantaneous and spontaneous explosion which creates excessive pressure and a knock. However, detonation in a Diesel engine is generally an instantaneous explosion of a greater than normal quantity of fuel in the cylinder, instead of only a portion of the fuel charge (as in the gasoline engine).

Whether combustion is normal or whether detonation occurs is determined by the amount of fuel which is ignited instantaneously. The greater the amount of fuel which ignites at one time, the greater the pressure rise and the more severe the knock. Detonation in a Diesel engine is generally caused by too much delay in ignition. The greater the delay, the greater the amount of fuel that accumulates in the cylinder before ignition. When the ignition point of the excess fuel is reached, all of this fuel ignites simultaneously, causing extremely high pressures in the cylinder and an undesirable knock. Thus, detonation in a Diesel, generally occurs at what is normally considered the start of the second phase of combustion instead of during the final phase, as in a gasoline engine. Detonation in a Diesel engine may occur when the engine is not warmed-up sufficiently, when fuel injection is timed too early, or when leaking injection valves permit excessive fuel to accumulate in the cylinder.

Even though it must have the ability to resist detonation, Diesel fuel must ignite spontaneously at the proper time under the pressure and temperature conditions existing in the cylinder. The ease with which a Diesel fuel oil will ignite and the manner in which it burns determine the ignition quality of the fuel. The ignition quality of a fuel is determined by its cetane rating or cetane value. The cetane value of a fuel is a measure of the ease with which the fuel will ignite. The cetane rating of any given fuel is identified by its "cetane number." The higher the cetane number, the less lag there is between the time the fuel enters the cylinder and the time it begins to burn.

The cetane rating of a Diesel fuel is determined in a manner similar to that used to determine the octane value of gasoline. However, the hydrocarbons used for the reference fuel are cetane and alpha-methyl-naphthaline. Cetane has an excellent ignition quality (100) and alpha-methyl-naphthaline has a very poor ignition quality (0). By comparing the performance of the reference fuel with that of a fuel the ignition quality of which is un-

known, the cetane rating or number of the latter can be determined. The cetane number represents the percentage of pure cetane in a reference fuel which will just match the ignition quality of the fuel being tested. The higher the cetane number, the quicker burning the fuel and the better the fuel from the standpoint of ignition and combustion.

While extremely important in a gasoline engine, the volatility of the fuel is of much less importance in a Diesel engine. Since fuel is injected into the cylinder of a Diesel engine after compression, there is no need for a considerable portion of the fuel to be vaporized in order to obtain a combustible mixture. Even though vaporization is not as important in a Diesel engine as in a gasoline engine, the volatility of Diesel fuel oil must be within certain limits. Generally, fuels with low volatility are most desirable for Diesel engines. However, if the volatility is too low, there is a tendency for the ignition to be delayed extensively, because of the greater time required for the injected fuel particles to start vaporizing. On the other hand, too volatile a fuel is likely to cause detonation and produce vapor troubles in the fuel injection system.

From your experience as a Fireman, you are already familiar with the term VISCOSITY, the resistance a liquid has to flow. Although a characteristic of all petroleum products, viscosity differs considerably in degree from one product to another. Remember, the higher the viscosity of a liquid, the greater the liquid's resistance to flow. The significance of the viscosity of any product depends upon the use of the product and the equipment in which it is used. Viscosity, of greatest importance in lubricating oils and lubricants, is a factor which also must be considered in the selection of Diesel fuel oil.

Resistance to flow is more important in Diesel fuel oil than in gasoline. While the viscosity of a Diesel fuel oil must be sufficiently low to permit the fuel to flow freely at the lowest temperature encountered, it must also be sufficiently high to aid in preventing leakage past the

closely fitted parts. The viscosity must be sufficiently high, too, for the fuel to properly lubricate the closely fitted parts of the injection equipment. The viscosity of the Diesel fuel oil determines the size of the injected fuel particles which, in turn, governs the degree of atomization and penetration of the injected fuel.

ENGINE FUEL SYSTEMS

The method of getting fuel into the cylinder is one of the major differences between gasoline and Diesel engines. As pointed out earlier, fuel for gasoline engines is mixed with air outside the cylinder and the mixture is then drawn into the cylinder and compressed. On the other hand, fuel for Diesel engines is injected or sprayed into the combustion space after the air is already compressed. The equipment which supplies fuel to the cylinders of a gasoline engine would necessarily be different from that of a Diesel engine. The basic differences in the fuel systems of the two types of engines have been pointed out in *Fireman,* NavPers 10520-A. Additional information is given here on the fuel systems of Diesel and gasoline engines.

Diesel Engine Fuel Injection Systems

There are several types of fuel injection systems in use. The function of each type is, however, the same.

FUNCTION OF AN INJECTION SYSTEM.—The primary function of a fuel injection system is to deliver fuel to the cylinders, under specified conditions. The conditions must be in accordance with the power requirements of the engine.

The first condition to be met is that of the injection equipment. The quantity of fuel injected determines the amount of energy available, through combustion, to the engine. Smooth engine operation and even distribution of the load between the cylinders depend upon the same volume of fuel being admitted to a particular cylinder each time it fires; and upon equal volumes of fuel being delivered to all cylinders of the engine. The measuring device of a fuel injection system must also be designed to

vary the amount of fuel being delivered, as changes in load and speed vary.

In addition to measuring the amount of fuel injected, the system must properly time injection to ensure efficient combustion, so maximum energy can be obtained from the fuel. Early injection tends to develop excessive cylinder pressures; and extremely early injection will cause knocking. Late injection tends to decrease power output; and, if extremely late, it will cause incomplete combustion. In many engines, fuel injection equipment is designed to vary the time of injection, as speed or load varies.

A fuel system must also control the rate of injection. The rate at which fuel is injected determines the rate of combustion. The rate of injection at the start should be low enough that excessive fuel does not accumulate in the cylinder during the initial ignition delay (before combustion begins). Injection should proceed at such a rate that the rise in combustion pressure is not excessive, yet the rate of injection must be such that fuel is introduced as rapidly as is permissible in order to obtain complete combustion. An incorrect rate of injection will affect engine operation in the same way as improper timing. If the rate of injection is too high, the results will be similar to those caused by an excessively early injection; if the rate is too low, the results will be similar to those caused by an excessively late injection.

A fuel injection system must increase the pressure of the fuel sufficiently to overcome compression pressures and to ensure proper distribution of the fuel injected into the combustion space. Proper distribution is essential if the fuel is to mix thoroughly with the air and burn efficiently. While pressure is a prime contributing factor, the distribution of the fuel is influenced in part, by "atomization" and "penetration" of the fuel. As used in connection with fuel injection, atomization means the breaking up of the fuel, as it enters the cylinder, into small particles which form a mist-like spray. Penetration is the distance through which the fuel particles are carried by the kinetic

energy imparted to them as they leave the injector or nozzle.

Atomization is obtained when the liquid fuel, under high pressure, passes through the small opening or openings in the injector or nozzle. As the fuel enters the combustion space, high velocity is developed because the pressure in the cylinder is lower than the fuel pressure. The friction created as the fuel passes through the air at high velocity causes the fuel to break up into small particles. Penetration of the fuel particles depends chiefly upon the viscosity of the fuel, the fuel-injection pressure, and the size of the opening through which the fuel enters the cylinder.

Fuel must be atomized into particles sufficiently small as to produce a satisfactory ignition delay period. However, if the atomization process reduces the size of the fuel particles too much, they will lack penetration; for, the smaller the particles the less the penetration. Lack of sufficient penetration results in the small particles of fuel igniting before they have been properly distributed. Since penetration and atomization tend to oppose each other, a compromise in the degree of each is necessary in the design of fuel injection equipment if uniform fuel distribution is to be obtained. The pressure required for efficient injection, and, in turn, proper distribution, is dependent upon the compression pressure in the cylinder, the size of the opening through which the fuel enters the combustion space, the shape of the combustion space, and the amount of turbulence created in the combustion space.

TYPES OF INJECTION SYSTEMS.—All of the various injection systems designed to perform the function described in the preceding section may be grouped under three main headings: INDIVIDUAL-PUMP SYSTEMS, COMMON-RAIL SYSTEMS, and the DISTRIBUTOR SYSTEM. The first two types of systems may be further classified, according to design: the original or basic systems, and the modified systems.

Fuel injection systems may also be classified as high-

or low-pressure systems. The common-rail and individual pump systems are of the high-pressure type and the distributor system is a low-pressure type.

Individual-pump injection systems of the original type include high-pressure pumps and pressure-operated spray valves or nozzles which are separate units. In some engines, only one pump and nozzle are provided for each cylinder. In other engines, such as the FM engine illustrated in figure 6–9, each cylinder is provided with two pumps and two nozzles. The arrangement of fuel injection pumps, their actuating camshafts, and the injection nozzles for one cylinder of an FM 38D engine are shown in figure 7–4.

Of all the fuel injection systems in use, the modified individual-pump system is the most compact. A high-pressure pump and an injection nozzle for each cylinder are combined into one unit. This type of unit is frequently referred to as a unit injector. The combined pump-nozzle

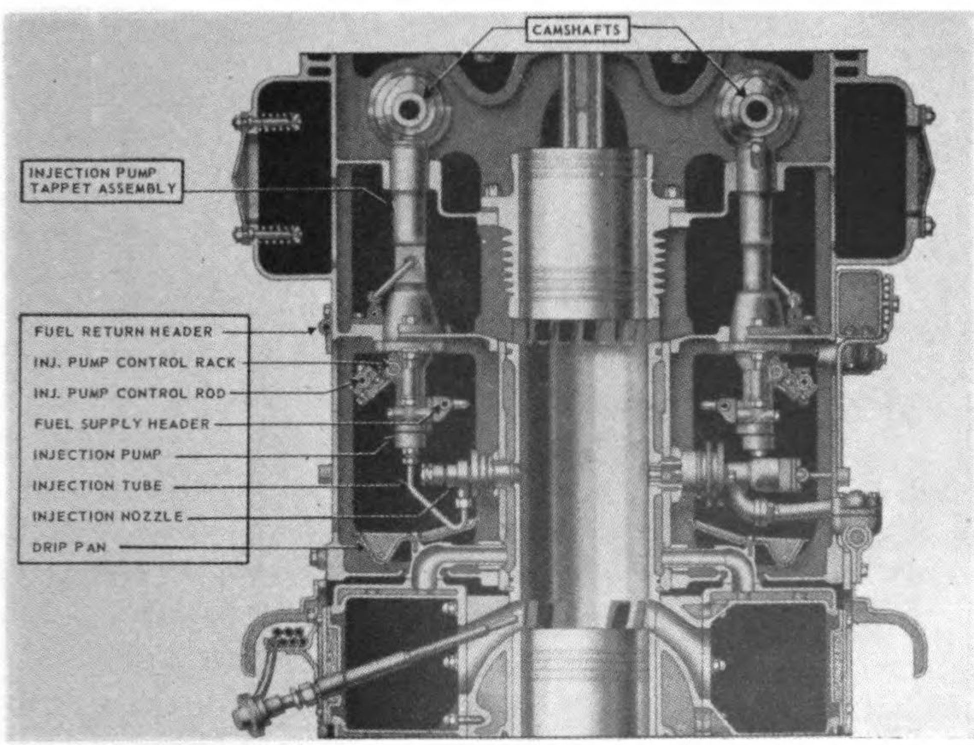


Figure 7–4.—Arrangement of separate pump and nozzle injection equipment.

unit fulfills all of the functions required of an injection system.

A cross-section of a cylinder head, showing a unit injector and its operating mechanism, can be found in *Fireman,* NavPers 10520–A. Also illustrated there are the other parts of a fuel supply system for a small Diesel engine.

The basic common-rail injection system consists of a high-pressure pump which discharges fuel into a common rail, or header, to which each fuel injector is connected. A spring-loaded, bypass valve on the header maintains a constant pressure in the system and returns all excess oil to the fuel supply tank. The fuel injectors are operated mechanically; and the amount of oil injected into a cylinder is controlled by the lift of the needle valve in the injector. The principal parts of a basic common-rail system are shown in figure 7–5.

The modified common-rail injection system, (sometimes identified as the controlled-pressure system), differs from

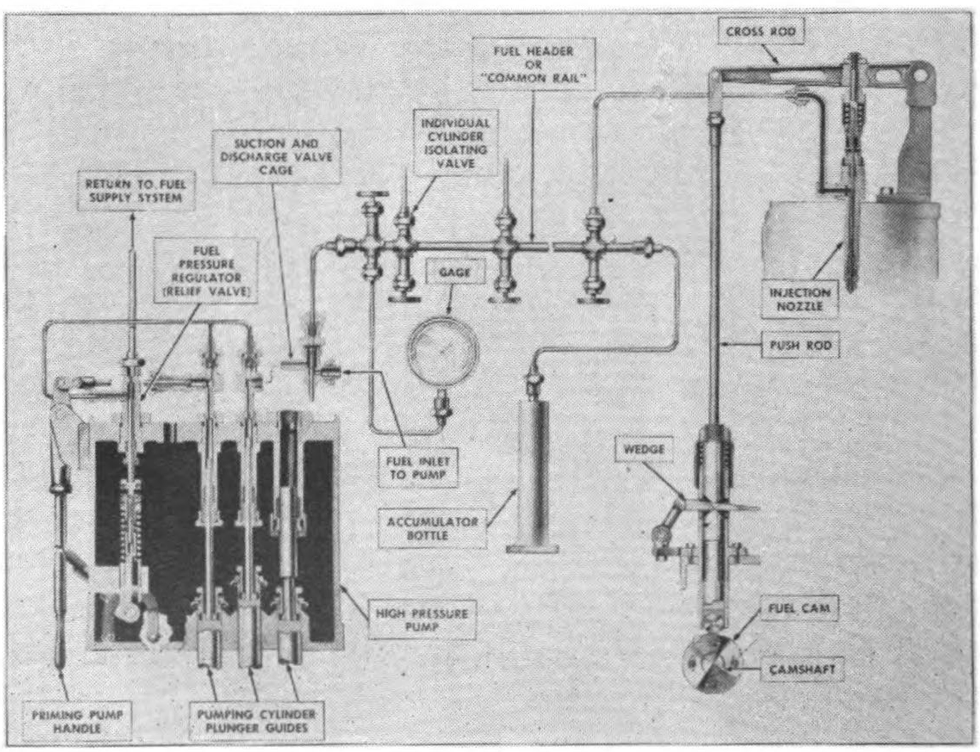


Figure 7–5.—Basic common-rail injection system (Cooper-Bessemer)

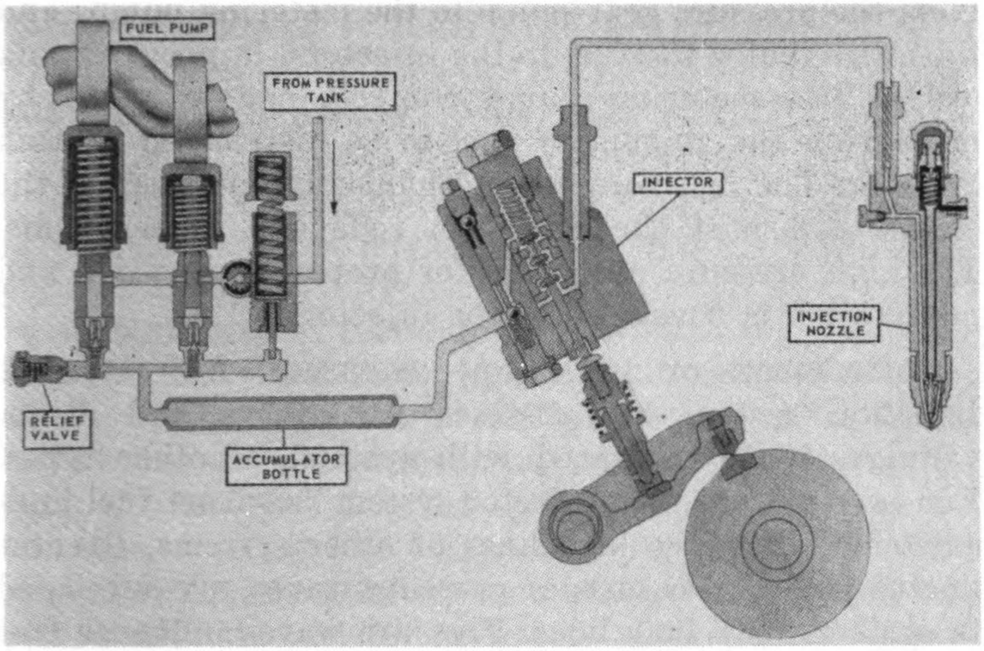


Figure 7–6.—Modified common-rail injection system (Cooper-Bessemer).

the basic system in that mechanically operated fuel injectors are included; and the nozzles are operated hydraulically instead of mechanically. The nozzles of the modified system, unlike those in the basic system, do not meter the fuel. Instead, the fuel is metered by the injectors. Pressure regulation is accomplished by the high-pressure pump, instead of by a pressure regulator. In brief, the modified common-rail system consists of a pump which builds up and controls operating pressure; fuel injectors which meter and distribute the fuel; the injection nozzles which introduce the fuel into the cylinders. The principal parts of a modified common-rail injection system are shown in figure 7–6.

The distributor injection system has characteristics similar to those of the unit injector and is sometimes so classified. However, the distributor-type system falls under the low-pressure classification.

In addition to the necessary filters, strainers, transfer pumps, and lines required in all fuel systems, the distributor injection system includes a metering pump, a distributor, and injectors. The distributor transfers fuel

from the pressure gear-pump to the metering pump; and then distributes the fuel to the injectors, in proper firing order. The metering pump controls engine speed by measuring the amount of fuel to be distributed to each cylinder. The injectors are mechanically operated by the engine camshaft through push rods and rocker arms. The high pressure necessary for proper atomization and penetration is developed in the injector.

COMPARISON OF INJECTION SYSTEMS.—Any type of injection system has distinct advantages and disadvantages when compared with systems of other types. For example, the unit-injector system has short fuel lines as compared to the long lines of other systems. Greater fluctuations in pressure, or pressure waves, are developed in systems with long lines. Pressure waves influence fuel discharge and atomization and may produce vibration which, in turn, may cause mechanical troubles. The short lines of unit-injector construction reduce the possibility of pressure waves. On the other hand, the high pressure created in a unit-injector system is a disadvantage since high pressure causes rapid wear of injector fuel-outlets. Also, because of high pressure there is a greater possibility of fuel leaks which, in turn, may result in dilution of the engine lubricating oil.

Injection systems of the common-rail type are suitable for low-speed, large-bore engines but are not suitable for high-speed, small-bore engines. While the common-rail system provides adequate control over the amount of fuel injected into the cylinders of larger engines, the system does not provide sufficiently accurate control for it to be used in engines with higher speed and smaller bore.

The low pressure of the distributor-type injection system is advantageous in that high pressure lines are not required in this system. Undesirable pressure waves are not characteristic of distributor-type systems. The relatively large inertia of the moving parts of a distributor system is a disadvantage in that it makes the system unsuitable for high-speed engines. One disadvantage of

earlier distributor systems was leakage from injectors, which resulted in dilution of lubricating oil. This trouble has been greatly reduced by the use of a new-type injector.

Gasoline Engine Fuel Systems

The fuel system of a gasoline engine is basically similar to that of a Diesel engine, except that a carburetor is used instead of injection equipment. While injection equipment handles fuel only, the carburetor handles both air and fuel. The carburetor must meet requirements similar to those of an injection system except that in the carburetor air is also involved. In brief, the carburetor must accurately meter fuel and air, and in varying percentages, according to engine requirements. The carburetor also functions to vaporize the fuel charge and then mix it with the air, in the proper ratio. The amount of fuel mixed with the air must be carefully regulated, and must change with the engine's different speeds and loads. The amount of fuel required by an engine which is warming-up is different from the amount required by an engine which has reached operating temperature. Special fuel adjustment is needed for rapid acceleration. All of these varying requirements are met automatically by the modern carburetor.

The basic principles of a carburetor are given in *Fireman,* NavPers 10520–A. Detailed information on carburetors and other parts of a gasoline engine fuel system is given in a more advanced training course for Enginemen.

Control of Engine Speed and Power

The speed and the power output of an engine are determined by the combustion process in the cylinders. Since combustion depends upon air and fuel, the speed and the output of an engine can be controlled by regulating the amounts of air and fuel supplied for the combustion process.

In Diesel engines, a varying amount of fuel is mixed with a constant amount of compressed air inside the cylinder. A full charge of air enters the cylinder during

each intake event. Since the quantity of air admitted is constant, combustion, and in turn, speed and power output of a Diesel engine are controlled by regulating the amount of fuel injected into the cylinders.

In a gasoline engine, speed and output are controlled by regulating the amount of air flowing into the cylinders of the engine. The carburetor is designed to measure the air flow. The amount of air and its velocity, in turn, control the quantity of fuel with which the air is mixed before the mixture enters the cylinders.

The quantity and velocity of air flowing to the cylinders is controlled by the throttle valve. By operating the valve, you admit more or less air to the engine, and the carburetor automatically supplies the gasoline necessary to maintain the correct fuel-air ratio. Regulation of fuel or air supply by manual throttle control is adequate when engine speed and output requirements remain relatively constant. However, the requirements of most engines used by the Navy vary because of fluctuating loads. The conditions under which a boat engine and the engine of a generating unit operate are examples of fluctuating loads. In rough weather, the propeller of a boat may leave the water and thereby relieve the engine of its load. In the case of a generating unit, the demands for electricity are variable. Manual throttle control is not adequate to hold engine speed reasonably constant during such fluctuations in load. For this reason, a speed control device, or governor, is provided to prevent the engine from overspeeding and to allow the engine to meet changing load conditions.

Even though it is not a part of the fuel system, a governor is directly related to this system since it functions to regulate speed by control of the fuel or of the fuel-air mixture, depending upon the type of engine. In Diesel engines, governors are connected in the linkage between the throttle and the fuel injectors. The governor acts, through the fuel injection equipment, to regulate the amount of fuel delivered to the cylinders. As a result,

the governor holds engine speed reasonably constant during fluctuations in load. Since the speed and output of a gasoline engine depend on the amount of fuel-air mixture available, governors, when used on these engines, are so connected that they control the amount of the mixture flowing from the carburetor to the intake manifold.

Governors, like carburetors and fuel injection equipment, seem somewhat complicated unless one has a thorough understanding of the construction and operating principles of the equipment. As you progress through the Engineman rating, you will acquire, through practical experience and study, the knowledge necessary to understand the factors which may seem complicated at the present. For the time being, it is sufficient to understand the relationship of speed-control devices to the fuel system of an engine. For this reason, the information on governors which is given in this course is general in nature. Additional information on governors, as well as on carburetors and injection equipment, is provided in subsequent training courses for the Engineman rating.

SPEED-REGULATING GOVERNORS FOR DIESEL ENGINES.—The type of load and the degree of control desired determine the kind of governor to be used on a Diesel engine. Since all governors used on Diesel engines control engine speed through the regulation of the quantity of fuel delivered to the cylinders, these governors may be classified under the general heading of speed-regulating governors. Governors used on Diesel engines may also be classified in various other ways, such as according to the function or functions performed, the forces utilized in operation, and means by which the governor operates the fuel-control mechanism.

Governors are designed to control engine speed under varying load conditions. Since the type of load and the degree of control desired vary from one type of installation to another, the primary function of a governor will depend upon the requirements of a particular installation.

Some installations require that engine speed remain constant from a no-load condition to a full-load condition. Governors which function to maintain a constant speed, regardless of load, are called "constant-speed" governors. Governors which maintain any desired engine speed between idle and maximum speeds are classified as "variable-speed" governors. Speed-control devices which are designed to keep an engine from exceeding a specified maximum speed and from dropping below a specified minimum speed are classified as "speed-limiting" governors. (In some cases, speed-limiting governors function only to limit maximum speed.) Some engine installations require a control device that will limit the load which the engine will handle at various speeds. Such devices are called "load-limiting" governors.

A governor may also be designed to perform two or more of the functions just listed. In such a case, the operating mechanisms which perform the various functions are incorporated in a single unit.

In most of the governors installed on Diesel engines used by the Navy, the centrifugal force of rotating weights (fly-balls) and the tension of a helical coil spring (or springs) are utilized in governor operation. On this basis, most of the governors used on Diesel engines are generally referred to as "spring-loaded centrifugal" governors.

In spring-loaded centrifugal governors, two forces oppose each other. One of these forces is the tension of a spring (or springs) which may be varied either by means of an adjusting device or by movement of the manual throttle. The other force is produced by the engine. Weights attached to the governor drive shaft are rotated, and a centrifugal force is created, when the shaft is driven by the engine. The size of the centrifugal force varies directly with the speed of the engine.

Transmitted to the injectors through a connecting linkage, the tension of the spring (or springs) tends to increase the amount of fuel delivered to the cylinders.

On the other hand, the centrifugal force of the rotating weights, through connecting linkage, tends to reduce the quantity of fuel injected. When the two opposing forces are equal, or balanced, the speed of the engine remains constant.

To illustrate how the centrifugal governor works, let us assume that an engine is operating under load; and that the opposing forces in the governor are balanced, so that the engine speed is constant. If the load is increased, the engine speed will decrease and a resultant reduction in the centrifugal force of the flyballs takes place. The spring tension then becomes the greater force and it acts on the fuel-control mechanism to increase the quantity of fuel delivered to the engine. The increase in fuel results in an increase in engine speed until balance of the forces is again reached.

When the load on an engine is reduced or removed, the engine speed increases and the centrifugal force within the governor increases. The centrifugal force then becomes greater than the spring tension and acts on the fuel control linkage to reduce the amount of fuel delivered to the cylinders. This causes the engine speed to decrease until a balance between the opposing forces is again reached and engine speed becomes constant.

Governors are also classified according to the method by which fuel-control mechanisms are regulated. In some cases, the centrifugal force of the rotating weights regulates the fuel supply directly, through a mechanical linkage which operates the fuel-control mechanism. Other governors are designed so that the centrifugal force of the rotating weights regulates the fuel supply indirectly, by moving a hydraulic pilot valve which controls oil pressure. Oil pressure is then exerted on either side of a power piston which operates the fuel-control mechanism.

Governors which regulate the fuel supply directly (through mechanical linkage) are called mechanical governors; and those which control the fuel supply indirectly (through oil pressure) are called hydraulic

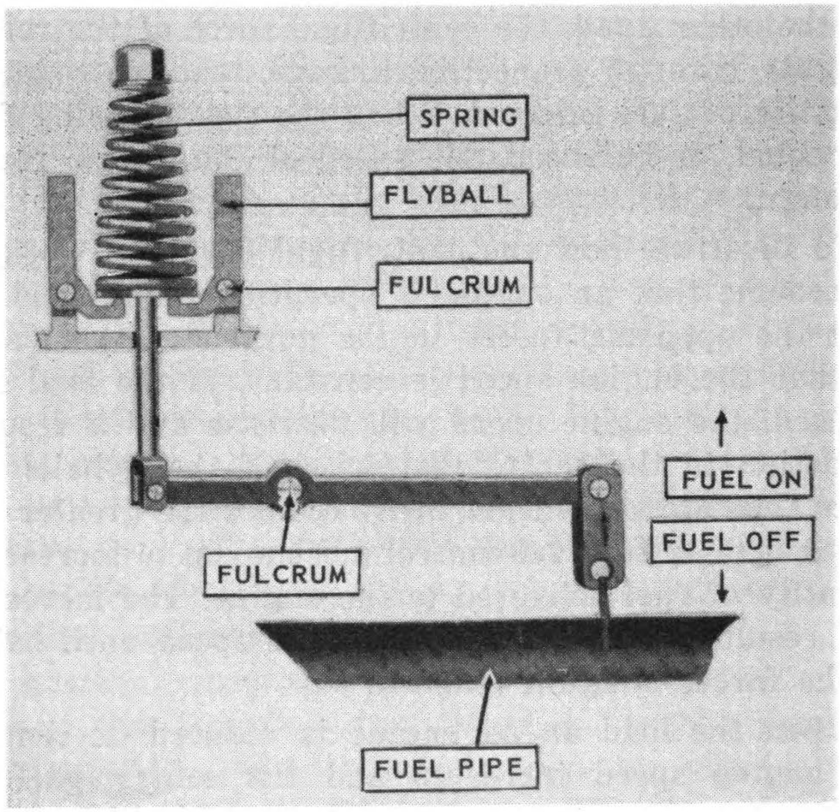


Figure 7–7.—Simple mechanical governor.

governors. Simple governors of the mechanical and hydraulic types are shown in figures 7–7 and 7–8, respectively.

Note that in the illustration of the mechanical governor the weights, or flyballs, are in an upright position. This indicates that the centrifugal force of the weights and the tension of the spring are balanced; in other words, the engine is operating at constant load and speed. In the case of the hydraulic governor, the positions of the parts indicate that the engine is responding to an increase in load with a resultant decrease in engine speed. Note that the weights tilt inward at the top. As engine speed decreases, the spring tension overcomes the centrifugal force of these rotating weights. When the spring tension is greater than the centrifugal force of the flyballs, the governor mechanism acts to permit oil under pressure to force the piston to increase the fuel valve opening. The

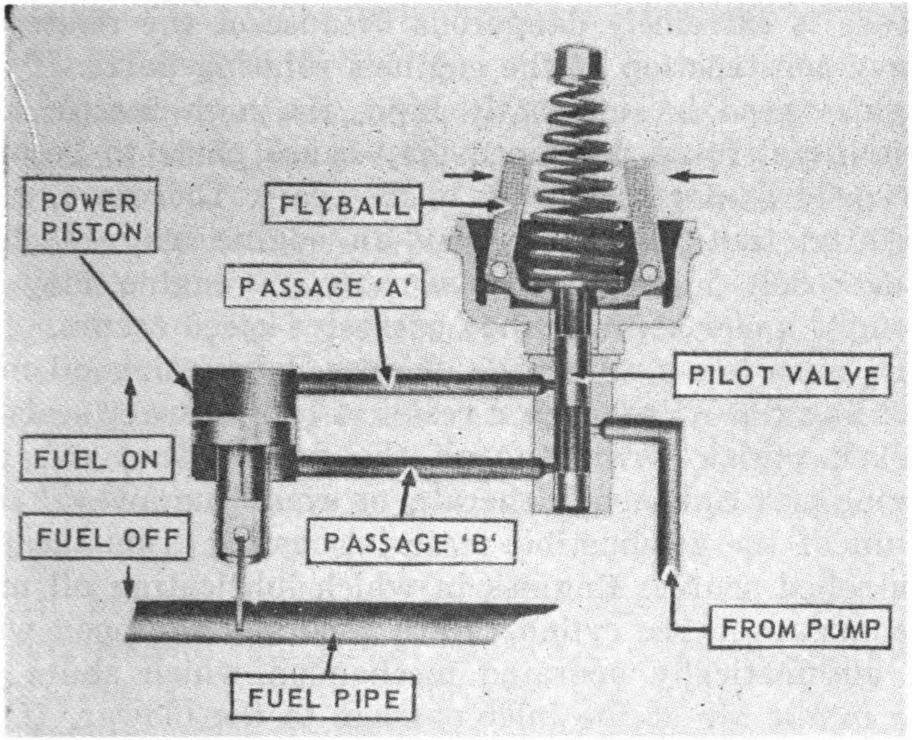


Figure 7–8.—Simple hydraulic governor.

increased fuel supply causes an increase in engine power output and speed. The governor regulates the fuel supply so that sufficient power is developed to handle the increase in load.

Hydraulic governors are more sensitive than those of the mechanical type. Also, the design of a hydraulic governor enables a comparatively small governing unit to control the fuel mechanism of a large engine. The mechanical governor is more commonly used on small engines, which do not require extremely close regulation of the fuel. Hydraulic governors are more suitable to larger engines, in which more accurate regulation of fuel is necessary.

OVERSPEED SAFETY DEVICES FOR DIESEL ENGINES.—Engines which are maintained in proper operating condition seldom reach speeds above those for which they are designed. However, there may be times when conditions occur which may result in speeds becoming excessively high. The operation of an engine at excessive

speeds is extremely dangerous because of the relatively heavy construction of the engine's rotating parts. If the engine speed is sufficiently high, the high inertia and centrifugal force developed may cause parts to become seriously damaged or even to fly apart. Therefore, it is essential that you know why an engine may reach a dangerously high speed; and how an engine may be brought under control when excessive speed occurs.

In some two-stroke cycle engines, lubricating oil may leak into the cylinders as a result of leaky blower seals or broken piping. Even though the fuel is shut off, the engine may continue to operate, or even "run away," as a result of the combustible material coming from the uncontrolled source. Engines in which lubricating oil may accumulate in the cylinders are generally equipped with an automatically operated mechanism which shuts off the intake air at the inlet passage to the blower. If no air shut-off mechanism is provided and shutting off the fuel will not stop an engine which is overspeeding, anything which can be placed over the engine's intake to stop air flow will stop the engine.

Excessive engine speeds are more commonly associated with an improperly functioning regulating governor than with lubricating oil accumulations in the cylinders. Whereas stopping the flow of intake air is used as a means of stopping an engine which is overspeeding because of lubricating oil in the cylinders, a means of shutting off or decreasing the fuel supply to the cylinders is more commonly used to accomplish an emergency shutdown or reduction of engine speed when the regulating governor fails to function properly.

Shutting off the fuel supply to the cylinders of an engine may be accomplished in various ways. The fuel-control mechanism may be forced to the "no fuel" position; the fuel line may be blocked by closing a valve; the pressure in the fuel injection line may be relieved by opening a valve; or, the mechanical movement of the injection pump may be prevented. These methods of

shutting off the fuel supply may be accomplished by either manual or automatic means.

Automatic operation of fuel and air control mechanisms is accomplished by overspeed safety devices. As emergency controls, these safety devices operate only in the event the regular speed governor fails to maintain engine speed within the maximum design limit. Devices which function to bring an overspeeding engine to a full stop by completely shutting off the fuel or air supply are generally called OVERSPEED TRIPS. Devices which function to reduce the excessive speed of an engine, but allow the engine to operate at safe speeds, are more commonly called OVERSPEED GOVERNORS.

All overspeed governors and trips depend upon a spring-loaded centrifugal governor element for their operation. In overspeed devices, the spring tension is sufficiently great to overbalance the centrifugal force of the weights until the engine speed rises above the desired maximum. When an excessive speed is reached, the centrifugal force overcomes the spring tension and operates the mechanism which stops or limits the fuel or air supply.

When a governor serves as the safety device, the actual operation of the fuel or air control mechanism by the centrifugal force may be accomplished directly, as in a mechanical governor; or indirectly, as in a hydraulic governor. In the case of an overspeed trip, the shut-off control is operated by a power spring. The spring is placed under tension when the trip is manually set, and held in place by a latch. If the maximum speed limit is exceeded, a spring-loaded centrifugal weight will move out and trip the latch, allowing the power spring to operate the shut-off mechanism.

GOVERNORS FOR GASOLINE ENGINES.—In many gasoline engines, the only regulation of speed is by manual operation of the throttle. Movement of the throttle actuates the throttle valve, which is usually a component part of the carburetor assembly. This valve is located on the out-

let side of the carburetor, at the entrance to the intake manifold. The position of the throttle valve controls the amount of fuel-air mixture which enters the manifold. While manual control of the fuel-air mixture is adequate in many cases, it is desirable in some installations to have a governor which regulates the fuel-air mixture to limit the engine to a predetermined maximum speed. The governors used on gasoline engines may be of a type similar to those used on Diesel engines, but they are more commonly of the VELOCITY, or VACUUM, type.

Governors of the velocity type are located between the carburetor and the intake manifold. The governor is operated by the velocity of the fuel-air mixture and by the intake manifold vacuum. In flowing from the carburetor to the manifold, the mixture passes the throttle valve, which is attached to a shaft mounted in an off-center position in the passage. This valve is seated at a slight angle so that the flowing mixture tends to close the valve. However, an accurately calibrated spring holds the valve open. In the event of overspeeding, the force of the mixture against the throttle valve overcomes the spring tension, and the valve closes and reduces the amount of mixture entering the cylinders. The vacuum of the intake manifold, acting on a piston connected to the throttle valve, stabilizes the throttle valve against the pressure of the mixture and prevents the valve from fluttering. Velocity-type governors do not affect engine performance until engine speed reaches the predetermined maximum speed for which the governor is adjusted.

SUMMARY

Even though Diesel and gasoline engines are similar in many respects, several differences exist. These differences are related to combustion and involve principally the fuel used and the heat necessary for combustion. A knowledge of these differences will make problems encountered in engine operation and maintenance more readily understood.

You should be familiar with the factors related to combustion and how these factors differ in Diesel and gasoline engines. Know the meaning of turbulence and precombustion and the significance of each to the combustion process of a Diesel engine. You should have a knowledge of engine fuels and their properties, as they apply to the combustion process and influence engine operation. Know why gasoline is the best fuel for engines operating on the Otto cycle and why fuel oil is more suitable for engines operating on the Diesel cycle. A knowledge of the principal differences in the methods by which fuel is supplied to the cylinders of Diesel and gasoline engines will be beneficial in understanding how and why engines of each type operate.

QUIZ

1. How does the manner in which fuel and air are admitted to the cylinders of Diesel and gasoline engines differ?
2. In a Diesel engine, how is the heat required for ignition generated?
3. If a Diesel engine and a gasoline engine each have a compression ratio at the upper limit, which engine will develop the greater pressure during the compression event?
4. Why is energy from an external source necessary for ignition in a gasoline engine?
5. What is the relationship between the pressure in the cylinder after the compression event and the power output of an engine?
6. What determines the highest practical compression ratio for a gasoline engine?
7. List three factors which determine when ignition should occur.
8. Is maximum power developed in the cylinder of an engine before or after the piston reaches TDC?
9. Does the time required for combustion vary with engine speed?
10. Why is the pressure developed in the cylinder of a gasoline engine less when ignition occurs later than when it occurs at the normal ignition time?
11. How is fuel related to the maximum-combustion pressure developed in the cylinder of a Diesel engine?
12. With respect to Diesel engines, what is meant by turbulence?
13. Why is turbulence necessary in a cylinder of a Diesel engine?
14. What two parts of a combustion space may include design features which aid in creating turbulence?

15. What is the principal constructional difference between an open combustion chamber and other types?
16. With respect to Diesel engines, what is precombustion?
17. Why is precombustion used in some engines?
18. In engines equipped with precombustion chambers, where is the major portion of the injected fuel burned?
19. Which characteristic of gasoline determines how much fuel will be vaporized?
20. What is meant by vapor lock?
21. In addition to difficulty in starting the engine, name two troubles which may occur if the gasoline is not completely vaporized when it enters the combustion space.
22. Name two symptoms of detonation which occur during engine operation.
23. With respect to the phases of combustion, when will detonation occur in a gasoline engine; in a Diesel engine?
24. In general, what causes detonation in a gasoline engine?
25. What is the principal factor which determines the octane rating of a fuel required for a given engine?
26. In a Diesel engine, what is meant by ignition delay?
27. In addition to the characteristics of the fuel, what factors determine the duration of ignition delay in a Diesel engine?
28. Are fuels with a low or high volatility most desirable for Diesel engines?

CHAPTER 8

ENGINE IGNITION SYSTEMS

The methods by which the fuel mixture is ignited in the cylinders of Diesel and gasoline engines differ as much as the methods of obtaining a combustible mixture in the cylinders of the two engines. You already have some familiarity with the compression ignition of Diesels and the spark ignition of gasoline engines. Both methods of ignition were introduced in *Fireman,* NavPers 10520–A, and reference has been made to each method earlier in this course. Additional information is given in this chapter on both methods of ignition and on the parts which make ignition possible in an engine.

COMPRESSION IGNITION

An ignition system, as such, is not commonly associated with Diesel engines. There is no one group of parts in a Diesel engine which functions only to cause ignition, as there is in a gasoline engine. However, a Diesel engine does have an "ignition system"; otherwise, combustion would not take place in the cylinders.

In a Diesel engine, the parts which may be considered as forming the ignition system are the piston, the cylinder liner, and the cylinder head. These parts are not commonly thought of as forming an ignition system since they are generally associated with other functions, such as forming the combustion space and transmitting power. Nevertheless, ignition in a Diesel engine depends upon the piston, the cylinder, and the head. These parts not

only form the space where combustion takes place but also provide the means by which the air is compressed to generate the heat necessary for self-ignition of the combustible mixture. (See combustion cycles, chapter 2.) In other words, both the source (air) of ignition heat and its generation (compression) are wholly within a Diesel engine.

This is not true of a gasoline engine because the combustion cycles of the two types of engines are different. In a gasoline engine, even though the piston, the cylinder, and the head form the combustion space, as in a Diesel engine, the heat necessary for ignition is caused by energy from a source external to the combustion space. The completion of the ignition process, involving the transformation of mechanical energy into electrical energy, and then into heat energy, requires several parts, each performing a specific function. The parts which make the transformation of energy and the system which they form are commonly thought of when reference is made to an ignition system. As an EN3, you are required to know the purpose and principles of operation of the spark-ignition systems which are common to the marine gasoline engines used by the Navy.

SPARK IGNITION

The spark which causes the ignition of the explosive mixture in the cylinders of a gasoline engine is produced when electricity is forced across a gap formed by two electrodes in the combustion chamber. The electrical ignition system furnishes the spark periodically to each cylinder, at a predetermined position of piston travel. In order to accomplish this function, an electrical ignition system must have, first of all, either a source of electrical energy or a means of developing electrical energy. In some cases, a storage battery is used as the source of energy; in other cases, a magneto generates electricity for the ignition system. The voltage from either a battery or a magneto is not sufficiently high to overcome the resistance set up by pressure in the combustion chamber

and to cause the proper spark in the gap. Therefore, it is essential that an ignition system include a device which increases the voltage of the electricity supplied to the system sufficiently to cause a "hot" spark in the gap of the spark plug. The device which performs this function is generally called an ignition coil or induction coil.

Since a spark must occur momentarily in each cylinder at a specific time, an ignition system must include a device which controls the timing of the flow of electricity to each cylinder. This control is accomplished by interrupting the flow of electricity from the source to the voltage-increasing device. The interruption of the flow of electricity also plays an important part in the process of increasing voltage. The interrupting device is generally called the breaker assembly. A device which will distribute electricity to the different cylinders in the proper firing order is also necessary. The part which performs this function is called the distributing mechanism. Of course, spark plugs to provide the gaps and wiring and switches to connect the parts of the system are essential to complete an ignition system.

All ignition systems are basically the same, except for the source of electrical energy. The source of energy is frequently used as a basis for classifying ignition systems; thus, we have the battery-ignition system and the magneto-ignition system. Even though the two systems are similar in many respects, they differ considerably in the design and arrangement of some of the component parts. For this reason, the two systems are discussed here under separate headings.

Battery-Ignition System

The introduction to the electrical system of a gasoline engine presented in *Fireman,* NavPers 10520–A, contains brief descriptions of the main parts and circuits of a battery-ignition system. A schematic illustration of the system is also provided to show that the primary circuit includes the battery, the switch, the primary winding of the coil, the condenser, and the breaker assembly; and

that the secondary circuit includes the secondary winding of the coil, the distributor mechanism, and the spark plugs. Supplementary information is provided here on the parts of each of these circuits and on the operation of the system which they form.

SOURCE OF ELECTRICAL ENERGY.—The STORAGE BATTERY is the source of electromotive force which pushes current through the primary, or low-voltage, circuit of the system. The voltage of a storage battery, whether 6-, 12-, or 24-volts, is not sufficient to produce the proper spark in the cylinder of an engine. Therefore, the primary function of the battery in an ignition system is to energize the secondary or high-voltage winding of the ignition coil. (The construction and principles of operation of a storage battery are covered in chapter 2 of the Navy Training Course, *Basic Electricity*, NavPers 10086.)

While the battery is considered the source of energy in the battery-ignition system, other electrical parts are necessary if the battery is to perform its function. A GENERATOR is required to deliver low-voltage direct current to the battery. VOLTAGE REGULATORS are required to disconnect the generator from the battery when the output voltage of the generator is too low or too high. (If generator voltage is lower than battery voltage, the current will drain from the battery through the generator; if generator voltage is too high, the battery may be damaged.) The electrical system of most gasoline engines also includes an AMMETER which enables the operator to check the functioning of the system. *Basic Electricity*, NavPers 10086, provides information on voltage regulators, ammeters, and direct-current generators in chapters 7, 9, and 10, respectively.

INCREASE OF VOLTAGE (IGNITION COIL).—The ignition coil includes parts of two circuits: the PRIMARY WINDING, of the low-voltage circuit; and the SECONDARY WINDING, of the high-voltage circuit. The primary purpose of the coil is to transform the low voltage of the primary circuit into the high voltage necessary to cause the electricity

to "jump the gap" in the cylinder. The ignition coil operates on the principle of electromagnetic induction; therefore, the coil is sometimes called an induction coil. A thorough knowledge of magnetism and induction, as explained in chapters 7 and 8 of *Basic Electricity,* will help you in understanding the principles of operation of an induction coil.

The two windings of an ignition coil are wound on a core of soft iron. The primary winding contains comparatively few turns of heavy wire; the secondary winding contains many turns of much smaller wire. Either winding can be next to the core; however, the secondary winding is wound next to the core in most modern coils. Insulated wire is used and the layers of turns are insulated from each other.

The core of a coil is made slightly longer than the winding so that most of the lines of magnetic force will encircle the winding. The core may consist of a bundle of soft iron wires or of thin soft iron strips or laminations.

Usually the coil has an outer cylindrical shell of laminated iron, which encloses the windings and serves as a conductor for the magnetic field. The core of the coil is usually insulated from the coil casing by a porcelain insulator in the base of the coil casing and by the coil cap, which generally contains the secondary terminal.

One end of the secondary winding is connected to the secondary or high-voltage terminal; the other end is either grounded in the coil or connected to the primary terminal and grounded through the primary circuit. The construction of one type of ignition coil is shown in figure 8–1.

An ignition coil depends on the inductive effect of the magnetism produced by the current in the primary winding to induce a high voltage in the secondary winding. The inductive effect of the two-winding coil is known as mutual induction. (See chapter 8, *Basic Electricity,* NavPers 10086.)

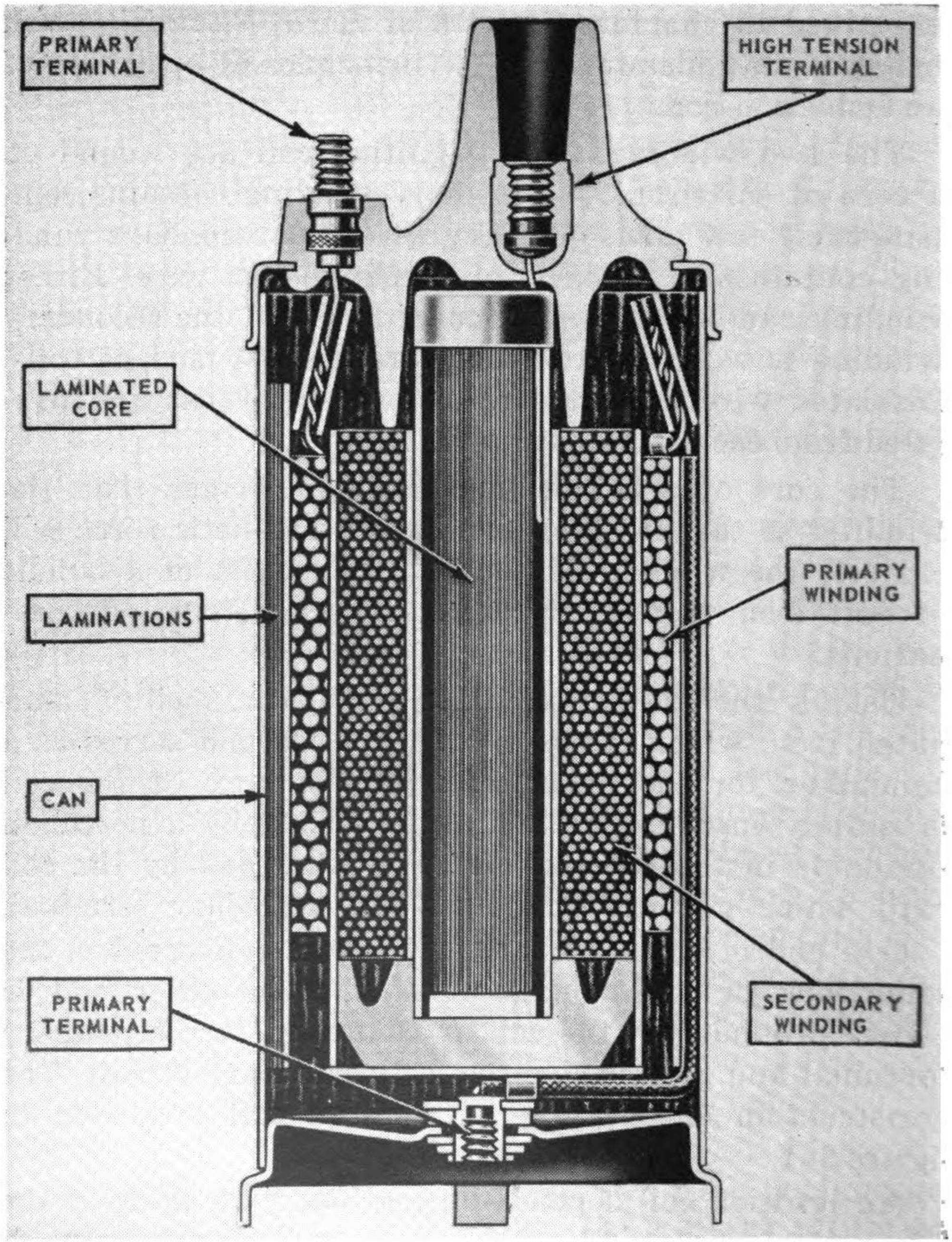


Figure 8–1.—Construction of an ignition coil (Auto-Lite).

A voltage is induced in the secondary winding when the core is magnetized by a current flow in the primary winding. A much greater voltage is induced if the magnetic field is suddenly collapsed. Thus, the breaker assembly is provided to open the circuit and cause the core to be demagnetized whenever high voltage is required.

The magnitude of the voltage developed in the secondary circuit of an ignition coil depends on the ratio of the turns in the primary winding to the turns in the secondary winding. The larger the number of turns in the secondary, in comparison with the number of turns in the primary, the greater will be the voltage that is produced. The voltage in the secondary winding is produced only long enough to cause a spark in the gap; then, the primary circuit is closed. This momentary production of high voltage is sometimes called a high-voltage surge or impulse.

The voltage required to cause a spark in the cylinder will vary, depending upon such factors as compression pressure, engine speed, fuel-air ratio, spark plug temperature, and width of spark plug gap. Ignition coils are designed to increase voltage sufficiently high to produce the proper spark. The amount of high voltage produced will, of course, depend upon the particular coil involved. Some coils are designed to develop as much as 25,000 volts in circuits in which normal operating requirements may vary from 4,000 to 18,000 volts. The voltage obtainable, in excess of that necessary to meet normal requirements, ensures an electrical reserve sufficiently adequate to meet the demands of all conditions of operation. When a voltage of this magnitude is compared with the voltage supplied by a battery (6, 12, or 24), it is readily understandable why the voltage developed by an ignition coil is classed as "high."

From the preceding discussion, it is apparent that the ignition coil, and not the battery, produces the high voltage necessary for the production of a spark in the

combustion space. The battery simply energizes the primary circuit of the system.

Various types of ignition coils are manufactured and each type is supplied in several models. Each coil is designed with windings which make the coil suitable for use with a particular engine under specific operating conditions. No one coil is suitable for all types of operation because of the wide range in operating conditions and the difference in ignition requirements of different engines.

INTERRUPTION AND DISTRIBUTION OF CURRENT.—The term "distributor" is commonly used to identify an ignition system component which does more than just distribute current to the spark plugs. Generally, the distributor includes the breaker assembly, a condenser, a distributing mechanism, and a spark-control mechanism. Each of these components performs a specific function essential to the process of creating a spark and controlling its occurrence at the proper time in the cylinder of a gasoline engine. The parts which form the various devices in one type of distributor are shown in figure 8–2.

The function of the BREAKER ASSEMBLY is to open and close the low-voltage, or primary, circuit of an ignition system. As this circuit opens and closes, intermittent surges of current are supplied to the primary winding of the coil. When the circuit opens, the magnetic field collapses and causes a high-voltage surge or impulse to be induced in the secondary winding of the coil. The individual parts of one type of assembly which opens and closes the primary circuit are identified in figure 8–2. An assembled breaker mechanism is shown in figure 8–3. Note that the nomenclature of similar parts in the two mechanisms illustrated differs in some cases.

The main parts of a breaker assembly are the plate, the breaker lever or arm (movable), two breaker (contact) points (sometimes called breaker contacts), the

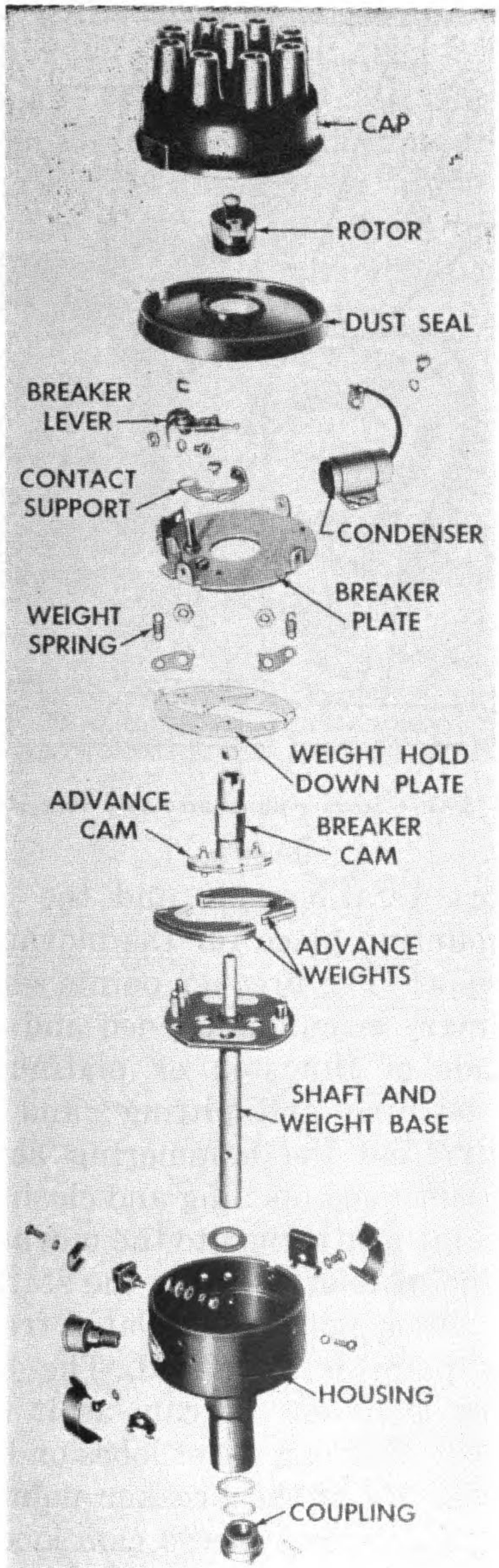


Figure 8–2.—Exploded view of a distributor (General Motors Corporation, Delco-Remy).

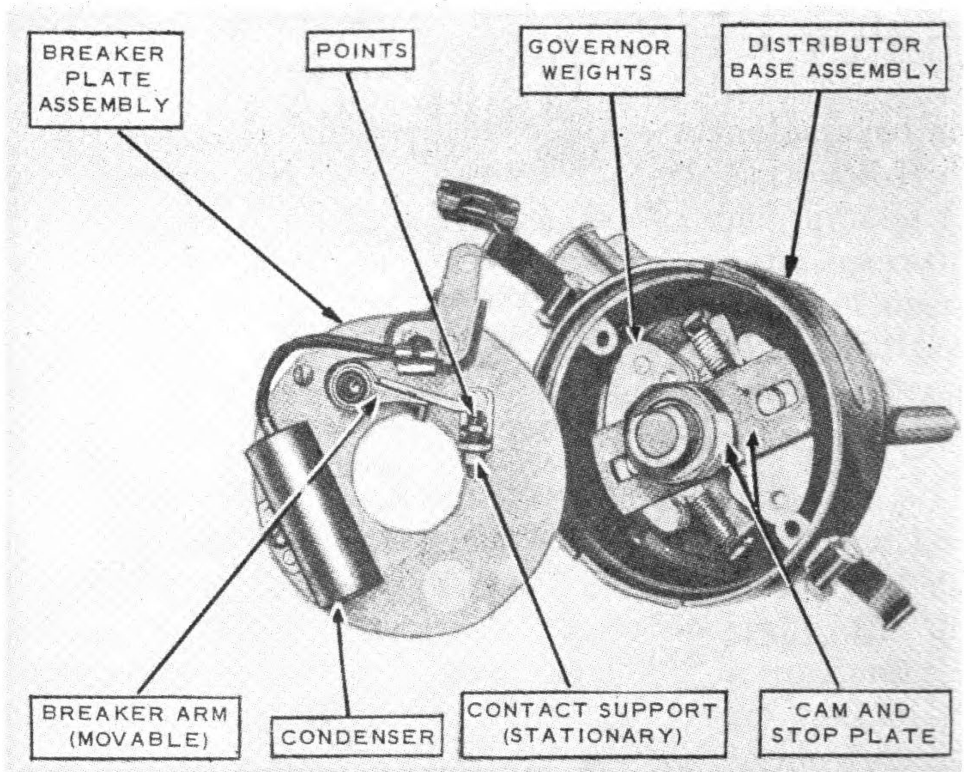


Figure 8—3.—Breaker-plate assembly (Chrysler M8).

contact support (stationary), and the cam. The plate serves as a mounting place for the movable arm and the stationary support. The breaker points serve as the point where the primary circuit is opened and closed. Breaker points are made of tungsten or platinum alloy. These metals resist burning and pitting; and they are hard enough to withstand the hammering action caused by the rapid and continued opening and closing of the points. One breaker point is attached to the movable arm and the other breaker point is attached to the stationary support. The movable contact point is insulated from the arm and the stationary point is grounded. The breaker arm is actuated by the lobes on the cam as it revolves on the distributor shaft. The number of lobes on the cam is equal to the number of times the breaker points are required to open during the cycle. When a cam lobe is not causing the breaker arm to move, the movable contact is held against the stationary contact, generally by spring ten-

sion. When a cam lobe pushes the movable arm, the breaker points separate and the circuit is opened.

Breaker assemblies may be of the single type or the double type. The assemblies shown in figures 8–2 and 8–3 are of the single type and have a single set of contact points. Assemblies of the double type include a second set of contact points. Double assemblies may be used in several ways, as illustrated in figure 8–4.

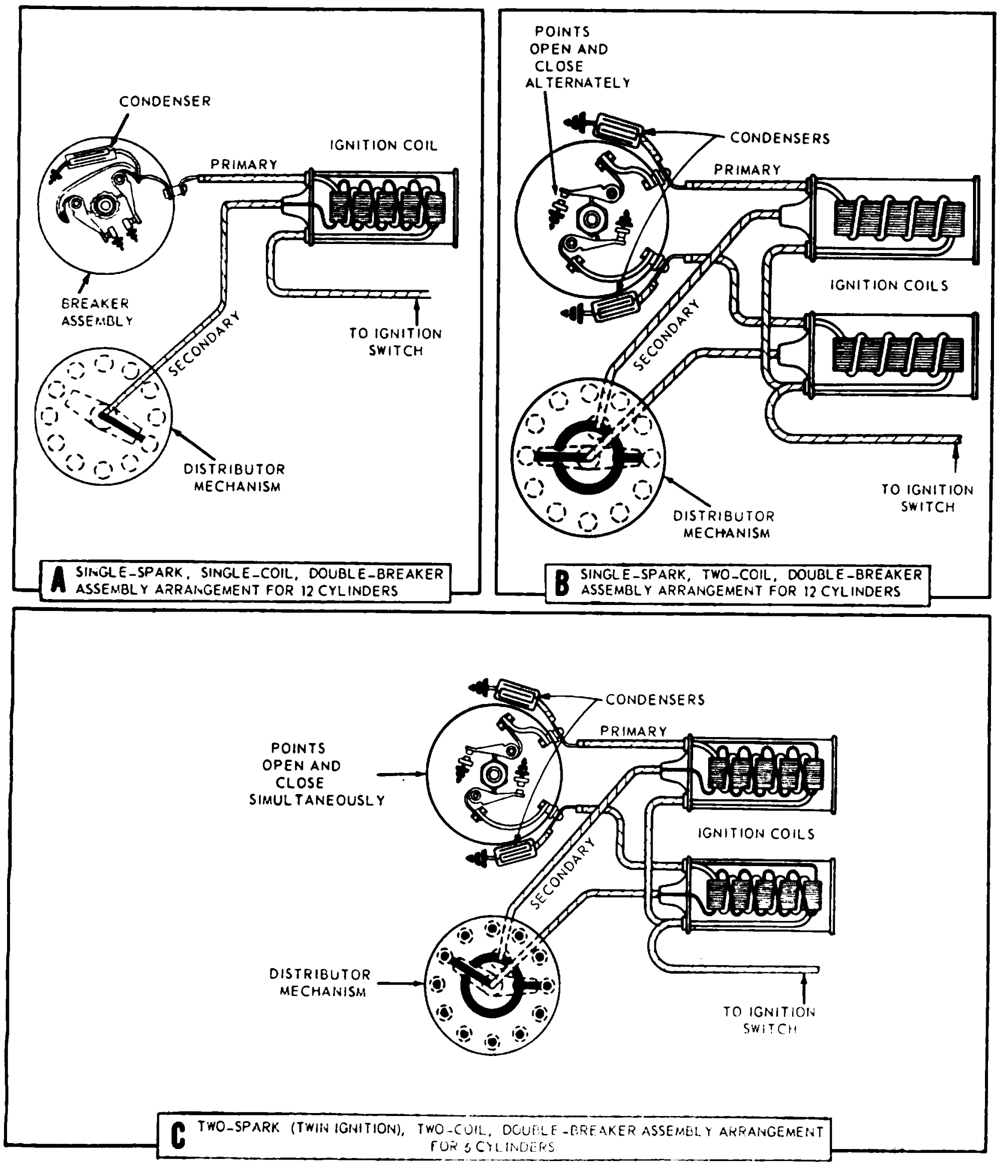


Figure 8–4.—Double-breaker assembly arrangements (General Motors Corporation, Delco-Remy).

A double-breaker assembly of the type shown in A is used with a single coil to produce a single spark. The two sets of points are connected in parallel. One set opens and closes slightly ahead of the other set. This results in an overlap in the opening and closing of the two sets, and permits the primary circuit to remain closed longer than would be possible with a single set of contact points. In some ignition systems, two coils are used with double-breaker assemblies, as shown in B. One set of points and one coil serves half of the engine cylinders, while the other half of the cylinders are served by the second set of points and the second coil. Since only a single spark is required at any one time during the cycle, the two sets of points open and close alternately.

In some systems, the two sets of contact points open and close simultaneously, as illustrated in C. An arrangement of this type is common to engines in which two plugs are provided for each cylinder. The two plugs are fired at the same time, one being fired by one set of points and one coil while the other is fired by the second set of points and the second coil. Ignition systems which provide two sparks simultaneously in one cylinder are frequently called twin, or dual, systems.

When the current is induced in the secondary winding of an ignition coil, a self-induced current is also created in the primary winding. In other words, as the breaker points begin to open, the collapsing of the magnetic field causes a momentary induced voltage in the primary winding. The magnitude of the voltage induced in the primary winding will depend upon the characteristics of the coil, but will generally be between 150 and 250 volts. While not nearly as high as that induced in the secondary winding, the voltage induced in the primary winding is considerably higher than that of a battery.

Because of the voltage induced in the primary winding, the current flowing in the primary circuit before the points open tends to continue to flow as the points open. Unless a device is included in the primary circuit to ab-

sorb this current, an arc is created between the contact points as they separate. An arc between the points consumes the energy stored momentarily in the coil in the form of magnetism and causes the points to burn, thus preventing proper ignition. A CONDENSER, which absorbs the surge of current and prevents arcing is inserted in the primary circuit. The location of such a condenser, with respect to the other parts of a distributor, can be seen in figures 8–2 and 8–3.

A condenser, which may be either flat or cylindrical in shape, is constructed of strips or sheets of tinfoil which are insulated from each other by thin sheets of paraffined paper or of mica. The alternate layers of tinfoil are connected in parallel to form two groups, and each group is provided with a terminal for connection into the primary circuit. One or two condensers may be used, depending upon whether the breaker assembly is of the single type or the double type. Condensers may be located either inside or outside the distributor housing, and should be connected as near the contact points as possible. (See fig. 8–3 and 8–4.)

The voltage induced in the primary circuit, as the breaker points open, charges the condenser instead of overcoming the resistance between the open contact points and forming an arc. The side of the condenser which receives the surge is temporarily charged negatively and the other side positively. The condenser instantly discharges, in a direction opposite to the flow of the original magnetizing current, through the primary winding and the battery, in an attempt to equalize the potential on the two sides of the condenser. This reversal in direction of current flow assists in quickly reducing the magnetism of the core, thus speeding the collapse of the lines of force and aiding in creating the maximum induced voltage in the secondary winding of the induction coil.

The current developed in the secondary winding must be directed to each cylinder in the proper firing order. The DISTRIBUTING MECHANISM which performs this func-

tion consists essentially of a rotor (distributor arm) and a cap (head) (fig. 8–2).

Distributor caps are made in a variety of designs to meet differing requirements, such as resistance to moisture and heat and fitting available mounting space. All caps have a center terminal which connects with the high-voltage terminal of the ignition coil; and as many terminals, equally spaced around the outer edge, as there are spark plugs to be fired. Each of the terminals, which are made of metal alloy, terminates on the inner side of the cap in the form of either a button or a pin.

The rotor is mounted on the upper end of the distributor shaft. The rotor directs the current from the high-voltage side of the coil to the proper spark plug terminal in the cap. The distributing mechanism may be considered as a revolving switch. The rotor closes the secondary circuit so that current from the high-voltage side of the coil will flow to the proper spark plug.

Distributor mechanisms may be classified according to the method used to complete the circuit between the rotor and the distributor-cap spark-plug terminals. In one method of completing the circuit, the rotor does not actually make contact with the spark-plug terminals in the cap. Instead, the end of the rotor electrode passes very close to the terminal pin and the electricity must jump this small gap in addition to that at the spark plug. Distributor mechanisms in which the rotor and plug terminals do not touch are classified as gap-type mechanisms. The term "air-gap" and "jump-spark" are sometimes used to identify gap-type mechanisms. Distributors used on most modern engines are of the gap type. The method of connecting the rotor to the secondary terminal, and the gap existing between the rotor and the plug terminal can be seen in the cross-section of the distributor shown in figure 8–5.

In another type of distributor mechanism, the end of the rotor makes a rubbing, or sliding, contact with the spark plug terminals in the cap; this type is known as

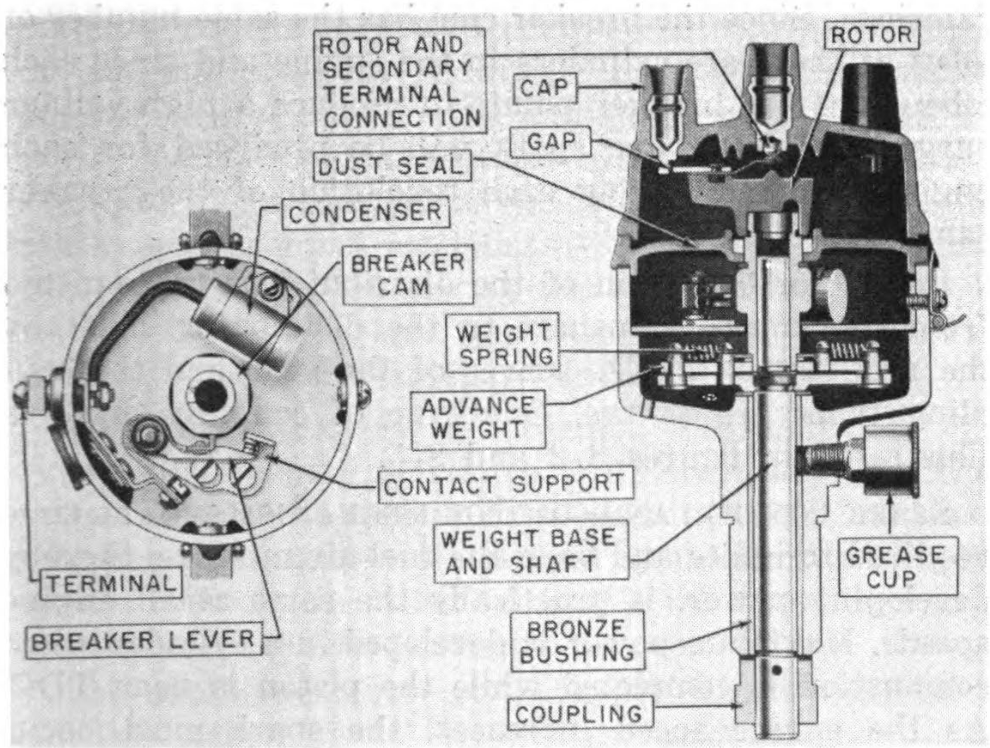


Figure 8–5.—Cross-section of a distributor (General Motors Corporation, Delco-Remy).

the contact-type distributor. The rotor makes contact with the plug terminals through either a metal button or a carbon brush.

The breaker-assembly cam and the distributor rotor are both driven by the DISTRIBUTOR SHAFT. (See fig. 8–2 and 8–5.) This is necessary in order to synchronize the operation of the two assemblies. These assemblies must be synchronized because the electrode on the rotor of a distributor mechanism must be in line with a spark-plug terminal each time the coil produces a high-voltage surge, which occurs each time the breaker-assembly cam causes the primary circuit to be interrupted.

In a 4-stroke cycle engine, the distributor rotor and the breaker-assembly cam are driven at one half engine speed because one half of the spark plugs must be fired during each revolution of the crankshaft. Proper speed of the distributor rotor and the breaker cam is attained by having the distributor shaft driven by the engine

camshaft. Since the breaker cam has the same number of lobes as there are cylinders in the engine and since each lobe opens the breaker points to produce a high-voltage surge of current, one spark will be produced for each engine cylinder, during each revolution of the breaker cam.

Power for operation of the distributor is transmitted from the engine camshaft to the distributor shaft by the DISTRIBUTOR DRIVE. Drives of the gear and the coupling types are in use. One type of coupling drive is illustrated in figures 8–2 and 8–5.

SPARK CONTROL AND CONTROL MECHANISMS.—The time required to ignite and burn the fuel-air mixture, thereby developing power, is practically the same at all engine speeds. Maximum power is developed in a cylinder when combustion is completed while the piston is near TDC. As the engine speed increases, the spark must occur earlier in the cycle in order to have combustion occur at the point in the cycle where it will be most effective.

In practically all battery-ignition systems, the time of spark occurrence, with respect to the position of the crankshaft and the piston, may be varied in one of two ways, while the engine is operating. Variation can be made either by moving the breaker assembly around the cam a few degrees or by moving the cam with respect to the breaker mechanism. If the breaker assembly is moved in the direction of cam rotation, the contact points will open later with respect to the crankshaft and piston positions and the spark will be RETARDED. On the other hand, if the breaker assembly is moved opposite to the direction of cam rotation, the points will open earlier with respect to crankshaft position and the spark will be ADVANCED. If the time of spark is varied by moving the cam instead of the breaker assembly, the advancing and retarding are reversed; that is, moving the cam in the direction of cam rotation will cause the points to open earlier, while moving the cam opposite to the direction of cam rotation will cause the points to open later.

Spark control may be accomplished by either manual or automatic means; however, most modern gasoline engines are equipped with automatic spark-control devices. Manual control requires skill and the continuous attention of the operator as the engine speed varies. Automatic spark-control mechanisms relieve the operator of the responsibility of gaging the correct time of spark; automatic devices also generally ensure greater fuel economy and better engine operation.

There are two types of automatic control devices. One type utilizes centrifugal force in its operation; the other is operated by the vacuum created in the intake manifold. In some cases, only a centrifugal mechanism is used for spark control; in other cases, both centrifugal and vacuum mechanisms are used.

The automatic CENTRIFUGAL spark-control mechanism consists principally of weights and springs mounted on a plate located in the distributor housing beneath the breaker assembly. The weights of a centrifugal spark-control mechanism are generally identified as governor, or advance, weights. The individual parts of a centrifugal spark-control device are shown in the exploded view of the distributor in figure 8–2; the control device as a unit and its relation to other distributor mechanisms are shown in figure 8–5. An assembled centrifugal mechanism is shown in figure 8–6.

The centrifugal mechanisms illustrated advance or retard the breaker-assembly cam as required by variations in engine speed. In the assembly shown in figure 8–6, the advance cam is integral with the breaker cam and the weight base is integral with the distributor shaft. At low or idling speeds, the springs hold the weights in the position illustrated; in other words, there is no spark advance and the spark occurs just before the piston reaches TDC during the compression event. As engine speed increases, the centrifugal force of the weights causes them to move out gradually against the spring tension. As the weights move out, they act on the ad-

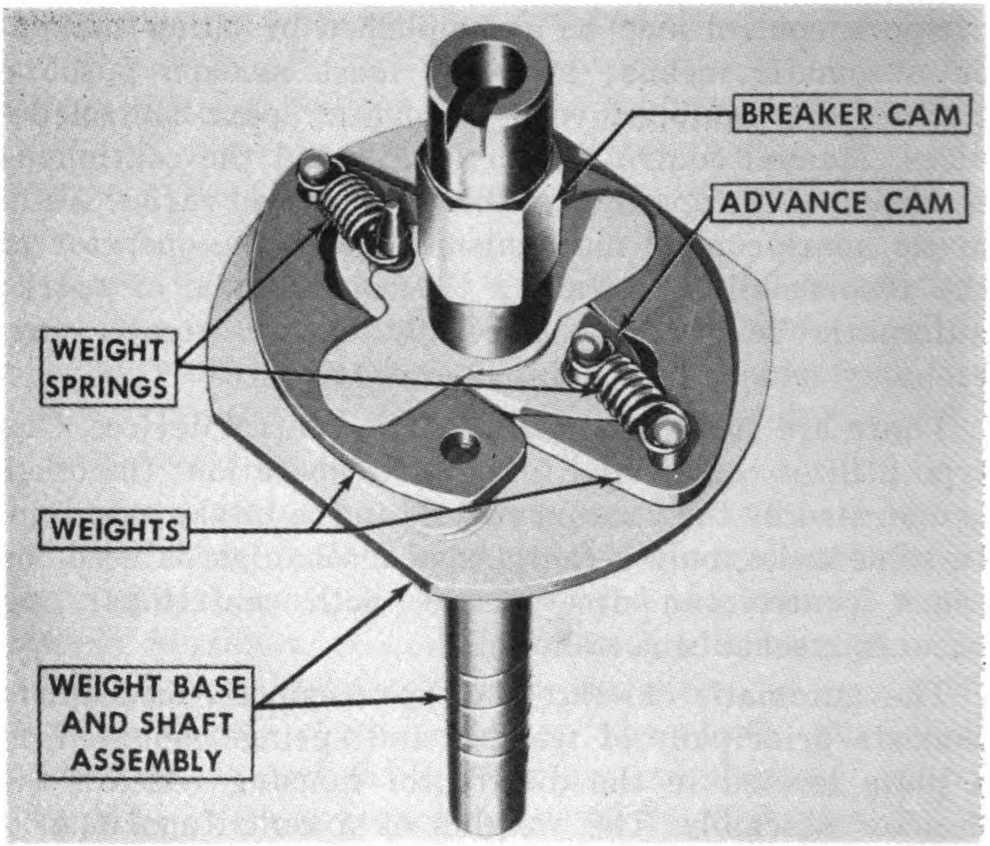


Figure 8—6.—Centrifugal spark-control mechanism (General Motors Corporation, Delco-Remy).

vance cam, which moves the breaker cam forward in relation to the distributor shaft, causing the spark to occur earlier. Cam advance is illustrated in figure 8–7. The illustration on the left shows the centrifugal mechanism in the idling, or no-advance (retard), position. The illustration on the right shows the cam in the high-speed or full-advance position.

The advance of the breaker cam causes the lobes to open and close the contact points of the breaker assembly earlier than they would at slower engine speeds; in other words, the spark is automatically timed, or advanced, to the correct position, in relation to engine speed. The springs of the centrifugal mechanism are calibrated so that it is possible to obtain predetermined variations in spark advance for various engine speeds. As engine

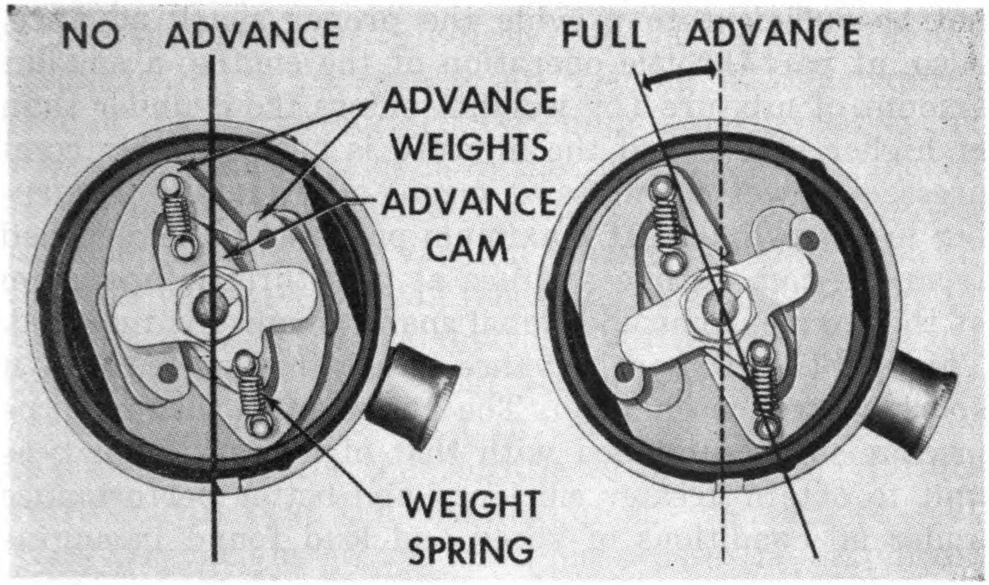


Figure 8—7.—Breaker cam in no-advance and full-advance positions (General Motors Corporation, Delco-Remy).

speed decreases, the centrifugal force decreases and the weights are gradually returned to their slow-speed position by the action of the springs. Thus, the spark is automatically retarded.

The centrifugal type control mechanism reacts only to changes in speed. In some installations, it is desirable to have spark control related to variations in engine load. When the load on an engine is increased, the throttle opening must be increased to provide the fuel-air mixture necessary for the required increase in power. The opposite is true when the load is decreased.

The vacuum in the manifold decreases as the load increases and increases as the load decreases. The varying vacuum in the manifold can be used to time the spark to meet the requirements of varying engine loads. Manifold vacuum may also be utilized to provide a greater spark advance than is provided by a centrifugal mechanism. Greater spark advance may be necessary in some engines when operation is at part-throttle. When the engine is operating at slow speeds, the centrifugal force developed in the centrifugal type control mechanism may

not be sufficient to provide the proper spark advance. Also, at part-throttle operation of the engine, a smaller amount of mixture (by weight) enters the cylinder than at higher speeds and the mixture is not so highly compressed. Lower compression means a lower rate of burning in the cylinder. If maximum power is to be obtained from the combustible mixture at part-throttle operation of the engine, some additional spark advance is required. This additional spark advance is obtained by a VACUUM spark-control mechanism. The action of a vacuum type mechanism is combined with that of a centrifugal type unit to obtain greater efficiency and better performance under all conditions of speed and load found in engine operation.

One vacuum unit commonly used to provide spark control on the basis of intake-manifold conditions consists principally of a spring-loaded diaphragm. This diaphragm is connected to the distributor by a linkage. In some cases, this linkage is connected to and rotates the complete distributor on its mounting. In other cases, the linkage is connected to and rotates the breaker assembly only. Both connections are illustrated in figure 8–8.

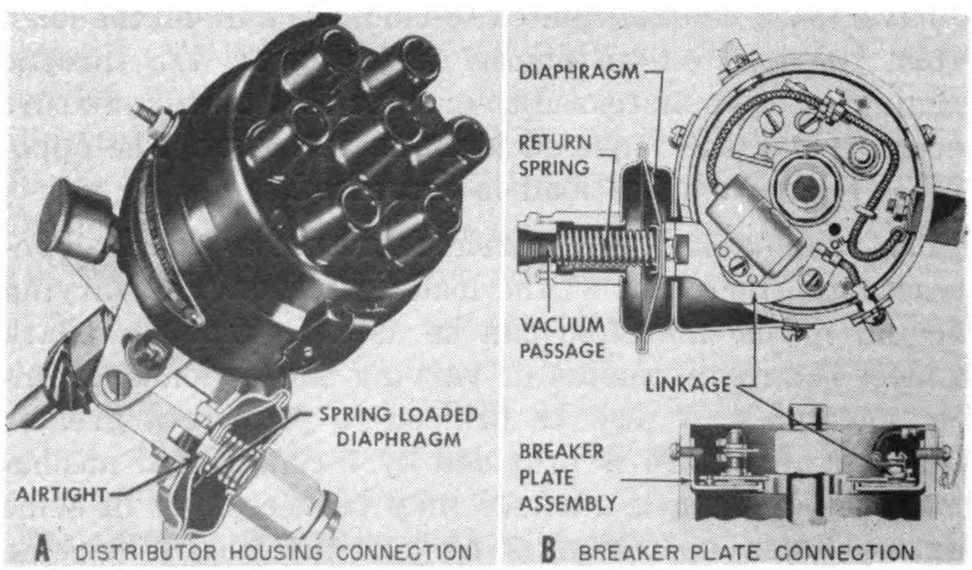


Figure 8–8.—Vacuum spark-control mechanisms with connecting linkage (General Motors Corporation, Delco-Remy).

The spring-loaded (air-tight) side of the diaphragm is connected by a passage to an opening in the manifold side of the carburetor. This opening is positioned so that when the throttle valve is in the "idle" position the opening is on the atmospheric (carburetor) side, and so that the opening is on the vacuum (manifold) side when the throttle valve is opened. When the engine is idling, the breaker plate is in the retarded position, with the diaphragm held in its normal position by the diaphragm spring. (See *A*, fig. 8–8.) In this position, there is no spark advance. As the throttle is opened, the throttle valve moves past the opening of the vacuum passage. Then the vacuum in the manifold causes the diaphragm of the spark-control unit to overcome the tension of the spring. The motion of the diaphragm is transmitted by the connecting linkage to the breaker assembly. This action provides the necessary spark advance. The amount of spark advance obtained is determined by the amount of intake-manifold vacuum, which, in turn, depends upon the position of the throttle valve. The vacuum opening on the manifold side of the throttle valve, the action of the vacuum in causing the diaphragm to compress the spring, and the consequent movement of the distributor are illustrated in figure 8–9.

AIR PATH OF CURRENT (SPARK GAP).—As the part which provides the air path of the current (the gap across which the current from the high-voltage side of the coil jumps to produce a spark), the SPARK PLUG might be considered as the final part in the secondary circuit of an ignition system. (However, the proper ground for the return of the current to the source should not be overlooked; see figure 9–18, *Fireman*, NavPers 10520–A.) There are two main types of spark plugs—those with ceramic insulators; those which are mica-insulated. The insulator part of a plug is sometimes identified as the core. A plug of the ceramic type is described briefly in the above-mentioned source. The parts of a spark plug are also illustrated there.

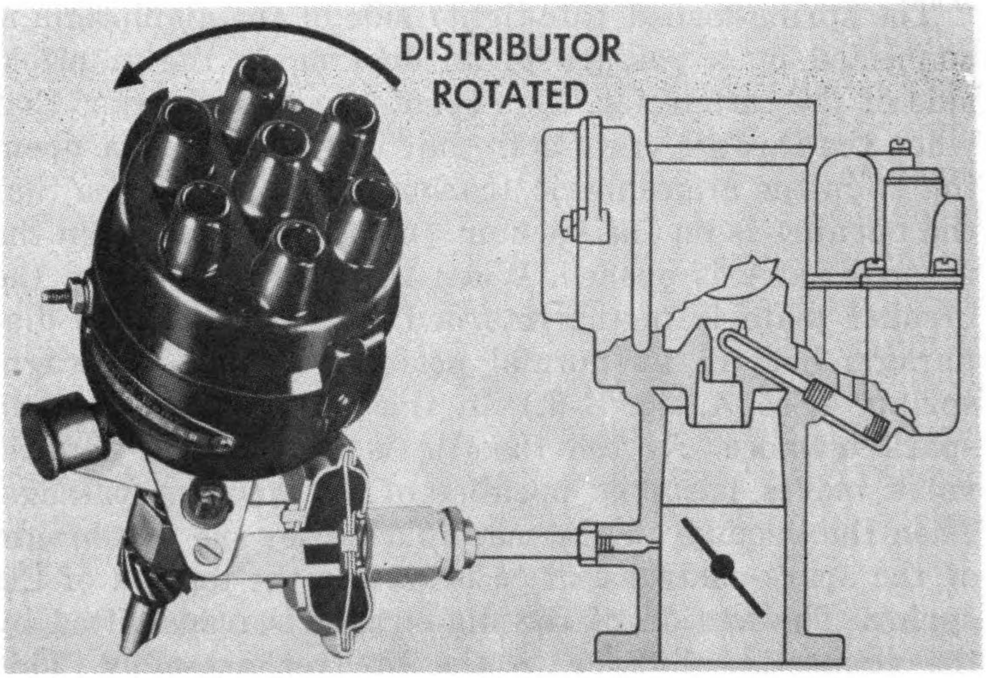


Figure 8—9.—Spark-advance caused by intake-manifold vacuum (General Motors Corporation, Delco-Remy).

While plugs with ceramic insulators are very common, some marine gasoline engines are equipped with mica-type plugs. The principal difference between the two types of plugs is in the core. Instead of ceramic material surrounding the center electrode, a mica cylinder enclosed with mica washers surrounds the electrode to form the core of a mica-type plug.

The conditions under which a spark plug operates are severe. A plug must be able to withstand high-voltage electricity, high compression pressures, and high temperatures. High compression pressures and high speeds, which result in high combustion temperatures, necessitate the use of a plug which will dissipate heat rapidly. The extent to which a plug will dissipate heat depends on the amount of the insulator exposed to the hot combustion gases. Engines which develop a great deal of heat require a plug with a short insulator, sometimes called a "cold" plug. Low compression or low speed engines require a plug with a long insulator, or a "hot" plug.

The heat characteristics of the engine usually determine the type of plug to be used in a given engine. However, conditions under which the engine operates may necessitate the use of a "hotter" or "colder" plug than is normally used. For example, an engine which is operating with a heavy load or one which is operating at a high speed for a long interval of time will require a "colder" plug than that used under less strenuous conditions of operation. The type of plug best suited for use in a particular engine under specified conditions of operation is determined by the engine manufacturer. Thus, when you are replacing and maintaining spark plugs, it is necessary that you use the specified plugs and follow the maintenance instructions relating to them.

PREVENTION OF ELECTRICAL INTERFERENCE (SHIELDING). In some engine installations, especially those operating near radio equipment, it is necessary to provide SHIELDING to prevent the radiation of high frequency energy from parts of the ignition system. An electromagnetic field surrounds an ignition wire each time a surge of current passes through the wire. The disturbance created by this field will ordinarily be picked up by radio receiving equipment operating in the vicinity, and will interfere with reception. In order to prevent such interference, ignition system components are shielded by enclosing the units in metal housings or in braided metal casings. All shielding must be firmly grounded so that the electrical energy absorbed by the shielding may be

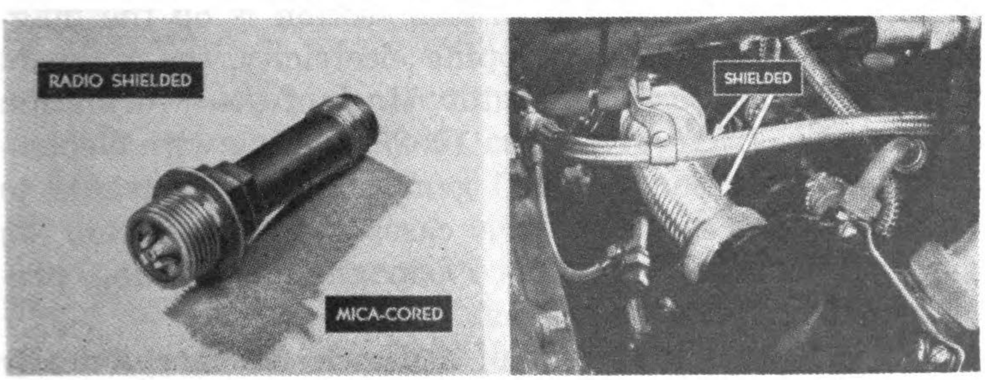


Figure 8–10.—Examples of ignition-system shielding.

properly dissipated. In addition to causing radio interference, the electrical energy given off by the ignition system, if it is not caught and grounded, may lead to detection of your ship by enemy radio direction finders. Examples of a radio-shielded mica-cored plug and of shielded ignition-wiring are shown in figure 8–10.

Magneto-Ignition Systems

As pointed out earlier, the source of the electricity is the primary difference between the two types of ignition systems. While a battery is simply a place to store energy and requires a generator as the initial source of energy, the magneto is designed to develop electricity. As in the case of the battery-ignition system, the magneto system must include a device to increase voltage. An interrupting device, or breaker assembly, is also required to ensure the proper timing of the electrical impulses; and a distributor is necessary to direct the impulses in the proper order to the cylinders. As in the battery-ignition system, two or more devices which perform different functions may be contained in a single component of the system. For example, the means for developing electricity; and the devices which increase the voltage developed, interrupt the primary circuit, and distribute the current may be contained within the magneto. In some systems, the distributing mechanism and the voltage-increasing device are separate from the magneto.

Since the components, except for the magneto, are basically the same in a magneto-ignition system and in a battery system, emphasis in this section is on the magneto. As a means for developing electricity, the magneto may be classified as a generator. Much of the information in *Basic Electricity*, NavPers 10086, dealing with electromagnetic induction and AC generators is applicable to magnetos. Since this is the case, the information on the electrical fundamentals of magneto operation presented in this course is brief.

MAGNETOS.—The magneto, a device for mechanically generating electricity with the aid of electromagnetic in-

duction, consists principally of an electrical conductor and a means for providing a magnetic field. Relative motion between the field and the conductor is necessary to induce voltage in the conductor. In the magneto, a permanent magnet supplies the magnetic field; a wire coil, or winding, is the conductor; and the engine provides the mechanical energy necessary for relative motion between the field and conductor.

Electromagnetic induction may be produced in a magneto in one of two ways: (1) by having a moving conductor "cut" the lines of magnetic force, or (2) by having a rotating magnet change the concentration of the magnetic field linked to a stationary conductor. In brief, magnetos may be classified on the basis of whether the conductor (magneto winding) revolves or remains stationary during operation of the magneto. Magnetos in which the winding moves while the magnets remain stationary are called armature-wound magnetos; those in which the winding remains stationary while the magnets move are called inductor-type magnetos.

Magnetos of the ARMATURE-WOUND type operate on the principle that an electric voltage is induced in a wire when the wire is moved across the magnetic field which exists between the pole of a magnet. If the wire is part of a complete circuit, current will flow in the wire. If the wire is then moved across the magnetic field in the opposite direction, the current will flow in the opposite direction. (*Basic Electricity*, NavPers 10086, chapters 8 and 12.) The application of this principle to a magneto is illustrated in figure 8–11.

The conductor, or winding, of an armature-type magneto is wound on a soft iron core. This winding, of insulated wire, forms a coil consisting of many rectangular loops. As one side of a loop (*A*, fig. 8–11), is going down through the magnetic field, the other side (*B*) is going up. Application of the "left-hand rule" shows that the current induced flows in one direction on one side of the loop and in the opposite direction on the other

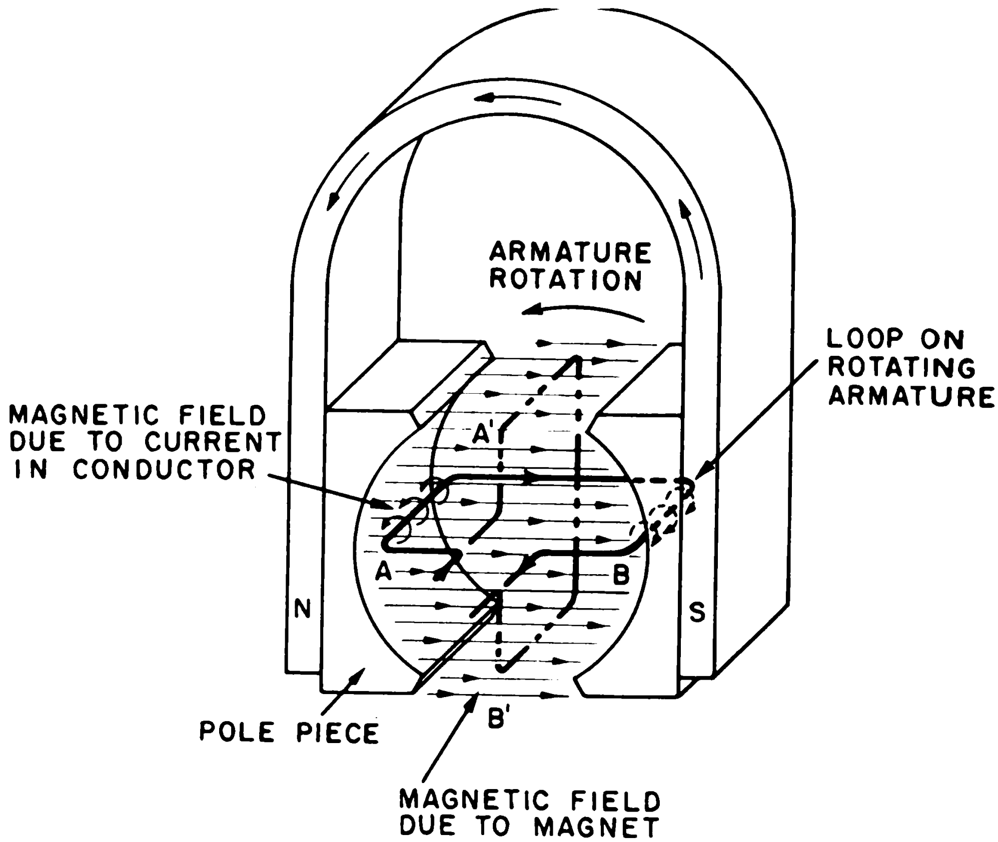


Figure 8—11.—Principle of an armature-wound magneto.

side. The voltages induced are added and cause the current to flow around the loop. When the loop reaches a position in its rotation where it is vertical and at right angles to the magnetic field (*A′B′*, fig. 8–11), the wire does not cut any lines of force in the magnetic field. Thus, no voltage is produced when the loop is in this position. After passing the vertical position, the sides of the loop cut the magnetic lines of force in the opposite direction. That is, the side that was going down against the lines of force now goes up; the one that was going up now goes down. This causes induced voltages in the opposite direction, which, when added, cause the flow of current through the loop to be reversed; that is, the flow of current in a loop of wire revolting in a magnetic field is alternating. All the loops in a magneto winding act similarly. The total magneto voltage is an accumulation of the individual loop voltages.

Armature-wound magnetos require either terminal contact buttons or slip rings, to carry the current from the rotating coil to a collector brush. One end of the winding is connected to the collector brush and the other end is grounded to the armature core, which, in turn, is grounded (through a brush) to the frame of the magneto.

In magnetos of the INDUCTOR TYPE, the winding is mounted on a stationary core and a magnetized rotor is used to direct the magnetic field through the winding, first in one direction, then in the other. The voltage is induced in the winding by the changing magnetic field. The manner in which the concentration of flux in an inductor-type magneto is varied is illustrated in figure 8–12.

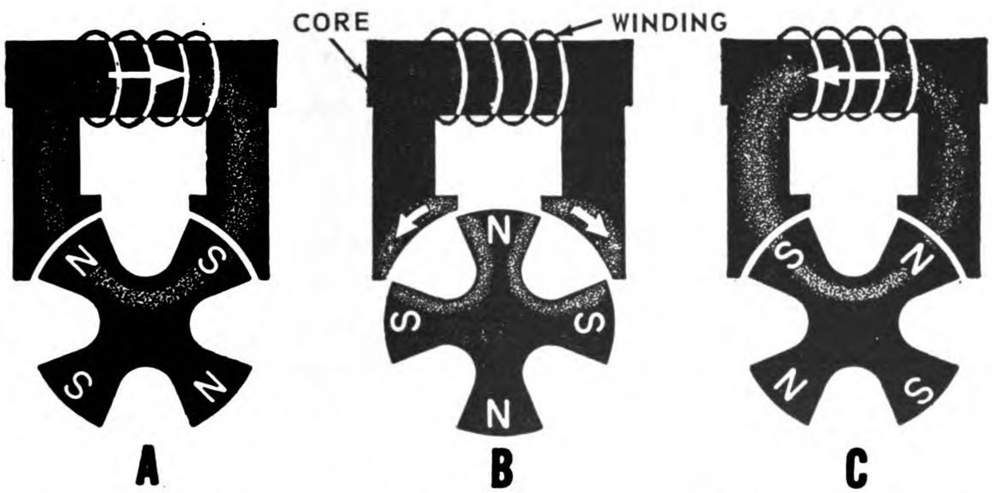


Figure 8–12.—Magnetic flux concentration at three positions of the magnet.

The magnet rotates between the pole shoes of an unmagnetized soft-iron core or yoke. The pole shoes are spaced so that they are simultaneously adjacent to two opposite (in terms of magnetic polarity) poles of the rotating magnet. As illustrated, the position of the rotating magnet poles with respect to the pole shoes determines the direction and the concentration of the flux in the core. When the poles of the magnet are in position *A*, the concentration of the magnetic lines of force through the core is at a maximum. As the magnet rotates,

the concentration of magnetic flux in the core diminishes, reaching zero at position *B*. As it continues to rotate, the magnet builds up the flux concentration, which reaches a maximum at position *C*. If a coil is wound around the core, the continuous change in magnetic flux concentration produces a change in the flux linkages through the coil, thereby inducing a voltage in the winding.

Brushes and slip rings are not necessary in the inductor-type magneto since the coil is stationary. Connection can be made directly to the coil.

MAGNETO MAGNETS.—Permanent magnets of extremely hard steel are used in magnetos. As pointed out in the preceding section, the magnet of an armature-wound magneto is STATIONARY, while the magnetic field in an inductor-type magneto is directed through the winding by a magnetized ROTATING element or rotor.

In an armature-wound magneto, conventional horseshoe-type magnets are generally used to form the frame. (See fig. 8–11.) Since several small magnets form a stronger magnetic field than a single large magnet of approximately the same weight, two or more small magnets are used together. To accumulate the magnetism of the separate magnets, like poles of the magnets are placed together. The inner surfaces of the pole pieces, shaped to fit the circular contour of the armature, project far enough inward so that only a very small clearance (air gap) exists between the pole pieces and the rotating armature. Since the magneto is usually attached to metal of the engine, a base of nonmagnetic material is placed under the ends of the magnets. The nonmagnetic material prevents the magnetic field between the poles from being diverted by the metal of the engine to which the magneto is attached.

In inductor-type magnetos, rotors of various designs are used to change the concentration of the magnetic field. One type of rotor is made of soft iron pieces which receive their magnetism from a permanent magnet of the horseshoe type. Another type of rotor consists of perma-

nent magnets of the bar type that are fastened between laminated poles. In some small engines, the rotor is a permanent magnet attached to the flywheel. One type of flywheel magneto is shown in figure 8–13.

The magneto illustrated is that of a 4-cylinder, 2-stroke cycle Johnson engine which is used to drive some P-500 pumps. The stationary component or magneto plate car-

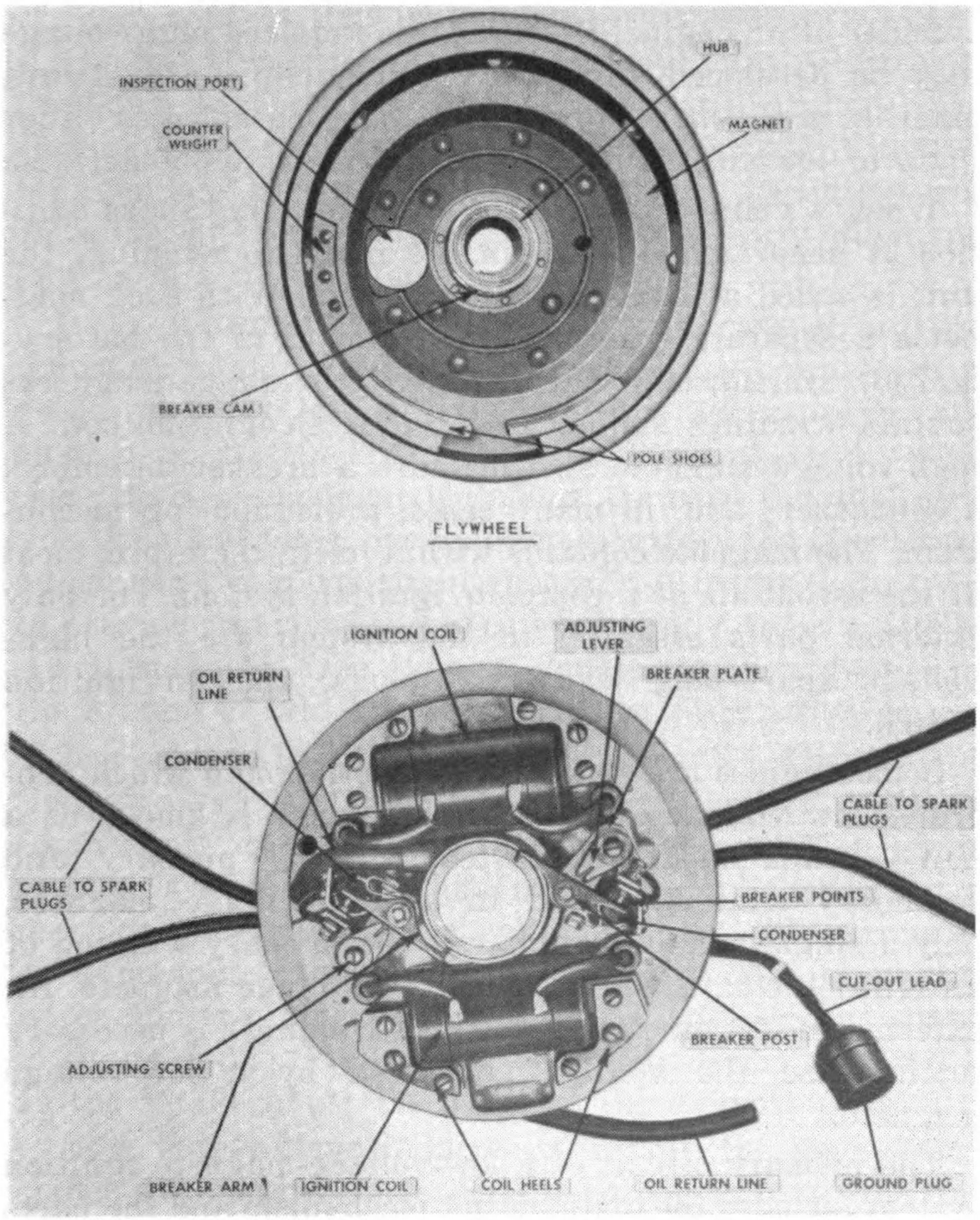


Figure 8–13.—Inductor-type flywheel magneto (Johnson Motors).

ries two coils and their integral iron cores and pole heels; two breaker assemblies; and two condensers. These parts make up two sets of components, each set serving two cylinders.

MAGNETO VOLTAGE.—Both armature-wound and inductor-type magnetos can be designed for low- or high-voltage operation. This does not mean that low-voltage produces the spark in some systems. All ignition systems require high voltage to produce a suitable spark in the cylinder of an engine. However, the required high voltage may be developed either in the magneto or by a unit external to the magneto. Magnetos are classified as either high- or low-voltage depending on the voltage generated.

When a voltage sufficiently high for jump-spark ignition is generated directly in the magneto winding, the unit is called a HIGH-VOLTAGE magneto. With such magnetos a separate ignition coil, as found in the battery-ignition system, is not necessary. High-voltage magnetos contain windings similar to those of an ignition coil. A high-voltage magneto also includes a breaker assembly; a condenser; and, in many cases, a distributing mechanism. The magneto contains within itself, therefore, most of the essentials of a complete ignition system. The only external parts essential to the system are the high-voltage spark-plug leads, the plugs, and an ignition switch.

Some engines are equipped with a magneto which generates low voltage only. Such a magneto is known as a LOW-VOLTAGE magneto. Instead of the primary and secondary winding found in a high-voltage magneto, only a single winding, similar to the primary winding of an ignition coil, is found in the low-voltage magneto. An external induction coil (secondary winding) is necessary to increase the voltage generated by a low-voltage magneto.

The primary circuit of a low-voltage-magneto ignition system includes the distributing mechanism and the parts common to the primary circuit of a high-voltage system.

The distributing mechanism may be either an integral part of the magneto or a separate unit. The primary current is transmitted from the low-voltage winding to the breaker assembly and to the distributor unit, where proper distribution takes place. From the distributor, current is delivered to the induction coil where voltage is increased. Induction coils in low-voltage magneto systems are located near the spark plugs. In some low-voltage magneto systems, a secondary coil is located at, or near, each of the spark plugs.

The use of a low-voltage magneto eliminates the need for long high-voltage leads to the spark plugs. The shorter leads reduce the electrical loss usually found in high-voltage systems. The problems of insulation and of radio shielding are not so great in a low-voltage system as in a high-voltage system.

DUAL MAGNETO IGNITION.—As in the case of battery-ignition systems, dual ignition is sometimes used in magneto systems to ensure positive firing and complete combustion of the fuel mixture in the cylinders. In some cases, two independent magnetos are used for dual ignition. In other cases, one magneto provides the two sparks which fire two plugs simultaneously. A magneto designed to provide two sparks at once is generally called a double-spark magneto. One type of double-spark magneto and the system of which it is a part are described here.

The system used as an example in this discussion is that of a V-type, 12-cylinder engine. However, the basic components used and the principles of operation of the ignition system are not affected by the cylinder arrangement or by the number of cylinders. The system consists of a magneto; two distributors; and two high-voltage wires and two plugs for each of the cylinders, as shown in figure 8–14. One plug in each cylinder is referred to as the intake plug; the other as the exhaust plug.

As a high-voltage inductor-type unit, the magneto includes two high-voltage coils, two condensers, and two sets of breaker points. One side of the magneto, with its

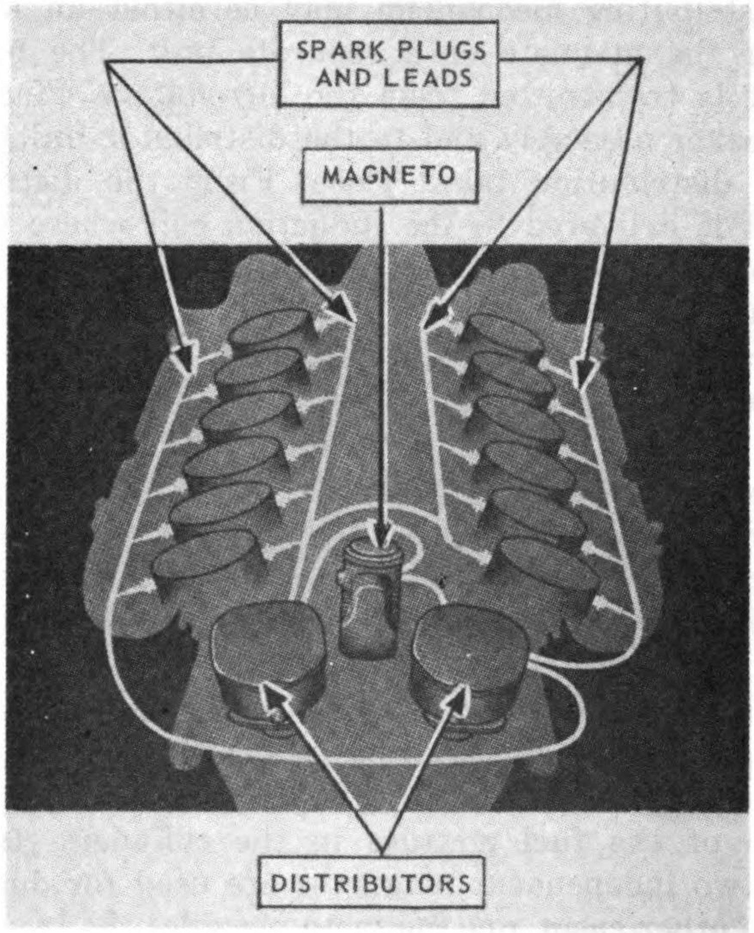


Figure 8—14.—Principal parts of a dual magneto ignition system.

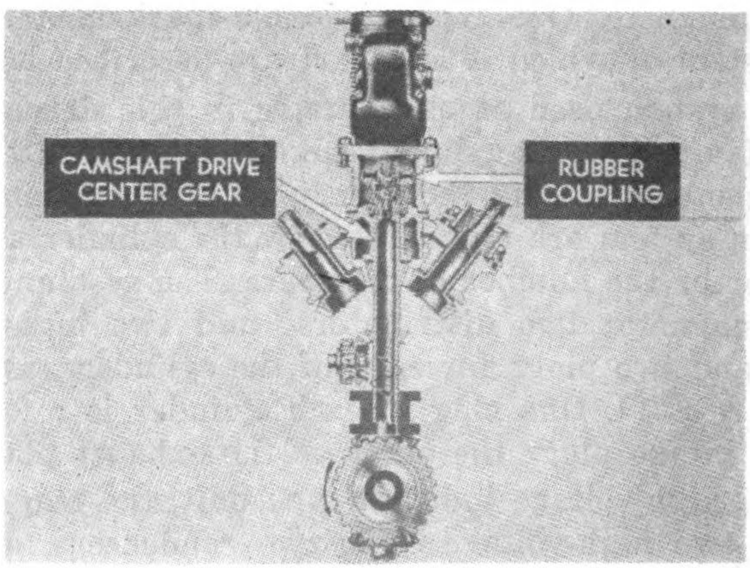


Figure 8—15.—Magneto drive.

breaker points, condenser, and coil, supplies current to the intake plugs of all cylinders. The other side of the magneto supplies current to the exhaust plugs of all cylinders. In effect, the complete unit is two magnetos in one housing, driven by one shaft. The drive for the dual magneto consists of the camshaft-drive center gear and a rubber coupling, as shown in figure 8–15.

Since both sides of a double-spark magneto are identical and since the same action takes place at the same time on both sides, this discussion deals primarily with only one side of the double-spark magneto. The circuits and the principal parts included in the double-spark magneto are illustrated in figure 8–16.

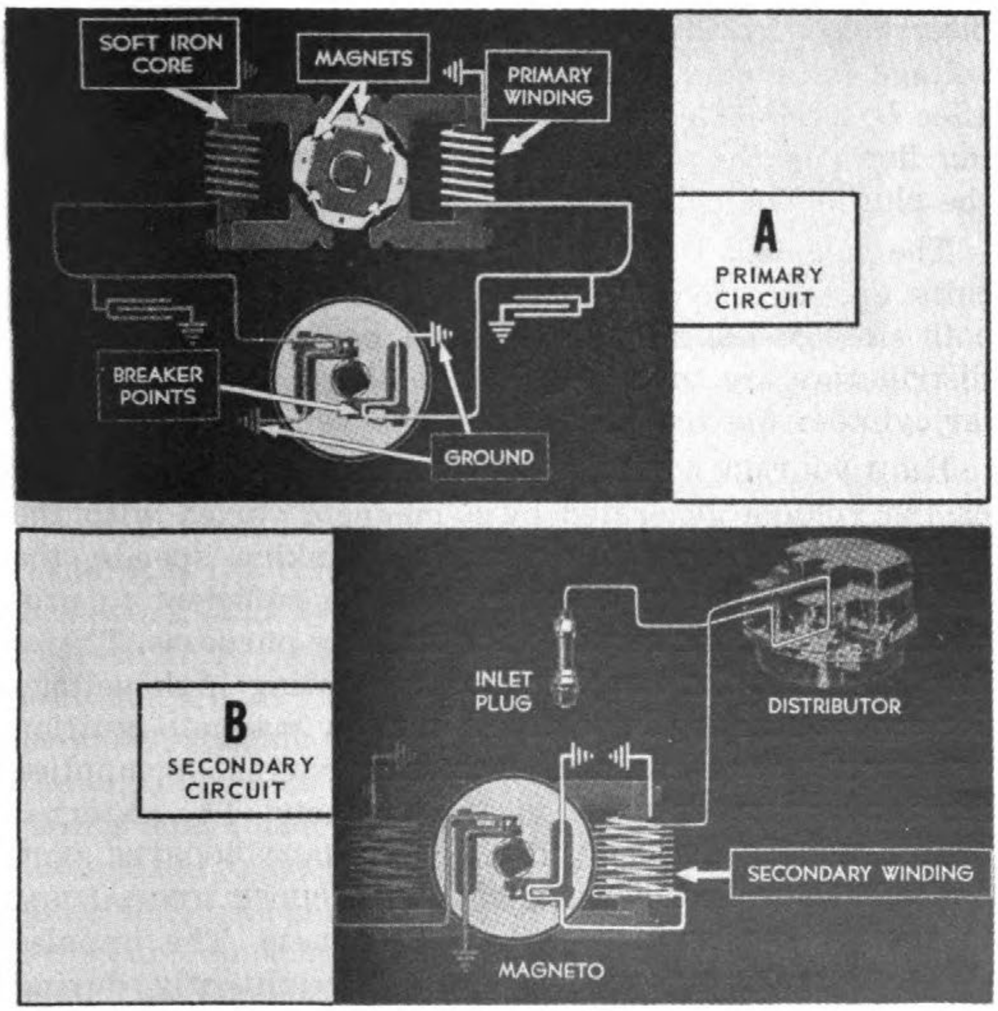


Figure 8–16.—Circuits in a double-spark magneto.

The primary circuits of the magneto are shown schematically in *A*, figure 8–16. When the magnets rotate between the two soft iron cores, low voltage is induced in the primary winding of each coil. One end of the primary winding is grounded directly to the body of the magneto. The wire from the other end of the winding conducts current through the breaker points to the ground.

The breaker points, located in a housing at the top of the magneto, are opened and closed by a rotating four-lobed cam which is mounted on the end of the drive shaft. A condenser is connected across each set of breaker points.

When the flow of current in the primary winding is interrupted by the opening of the breaker points, high voltage is induced in the secondary winding of the coil. (See *B*, fig. 8–16.) The current from the secondary winding flows to the distributor, by which it is directed to the plug in the cylinder which is ready to fire.

The cam and the breaker points in the duplicate circuits are arranged so that high voltage is induced on both sides of the magneto at the same instant. Since the distributors are timed together, both plugs of a particular cylinder fire together.

HIGH VOLTAGE AT LOW MAGNETO SPEEDS.—The intensity of the voltage generated by a magneto varies with the speed of the magneto. At engine-cranking speeds, the voltage developed by a magneto is not sufficient to produce the hot spark required for starting purposes. Therefore, a means for supplying or generating high voltage for engine-starting is provided in many magneto-ignition systems. In some cases, the necessary current is supplied from a source external to the magneto. The external source usually consists of a high-voltage BOOSTER COIL and a battery. In other systems, an IMPULSE MECHANISM is used in conjunction with the magneto. The impulse device increases magneto speed intermittently during engine-cranking.

The high-voltage booster coil used for starting purposes in a magneto-ignition system operates on a principle similar to that underlying the operation of the induction coil in a battery-ignition system. The primary current is supplied by a battery. The booster coil and battery are used only during the engine-cranking operation. The booster-coil circuit used with the dual-system described in the preceding section is illustrated in figure 8–17.

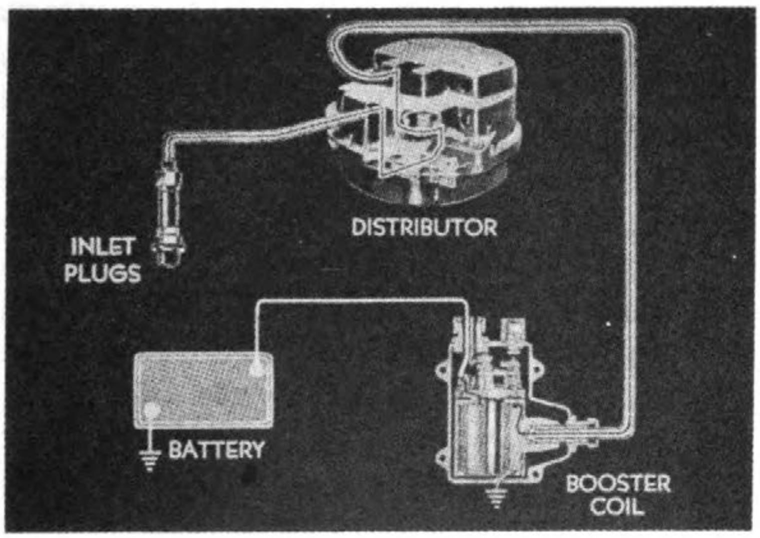


Figure 8–17.—Booster-coil circuit for a magneto-ignition system.

The booster coil illustrated in figure 8–17 is of the vibrator type. In addition to the primary and secondary windings, the coil contains a pair of contact points, an armature, and a condenser. When the circuit is closed, current from the battery flows through the contact points and the primary winding. This current flow through the primary winding develops a magnetic field which attracts the armature so that the contact points open. As the points open, the magnetic field collapses and a high-voltage surge is induced in the secondary winding. At the same time, the collapse of the magnetic field releases the armature so that the contact points close again. This cycle is repeated very rapidly, causing high-voltage surges to flow from the secondary winding.

Current from the booster coil is conducted to the booster electrode of the distributor rotor. As the rotor revolves, the booster electrode follows directly behind the magneto electrode, through which current flows when the engine is operating at normal speeds. The "trailing" booster electrode provides the slower (retarded) spark required when the engine is being cranked. An example of a two-electrode rotor is shown in figure 8–18.

In some magneto-ignition systems, high voltage is generated by the magneto during the cranking interval, but an IMPULSE MECHANISM is necessary to increase the armature (rotor) speed. Impulse mechanisms are commonly called impulse-starter couplings, or simply impulse couplings. Details of construction of these couplings vary greatly, but the principles of operation of all impulse-starter mechanisms are practically the same. Basically, an impulse mechanism is a mechanically-operated spring-and-rachet device which is mounted between the magneto drive from the engine and the magneto-driven shaft.

At cranking speeds, the spring is compressed and then released by a trigger arrangement each time a high-

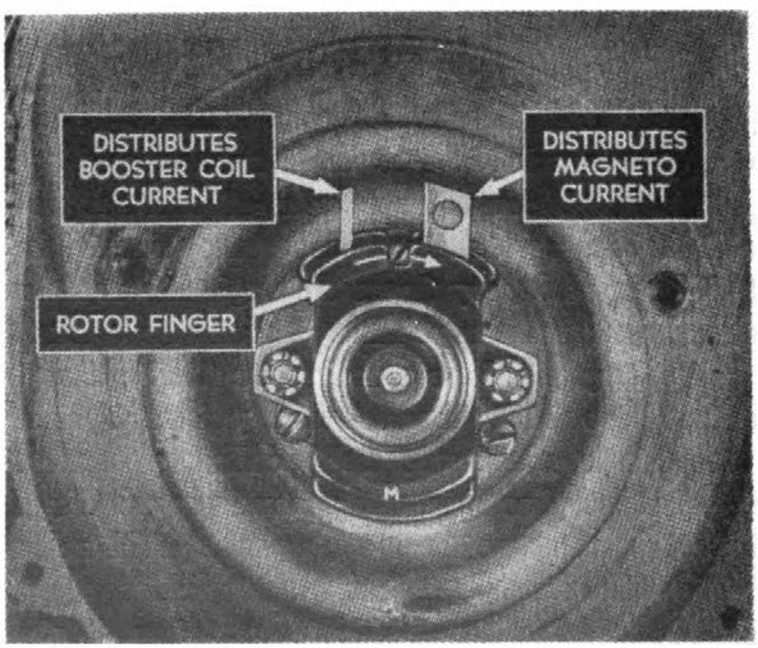


Figure 8–18.—Distributor rotor with booster-coil electrode.

voltage surge is required. When the compressed spring is released, the stored energy causes the mechanism to drive the magneto armature (rotor) at a high speed for about one-half revolution. The speed of the magneto is then sufficiently great to generate the high voltage required to produce the hot sparks necessary for starting. The mechanism sets and releases periodically, causing the speed of the armature (rotor) to be uneven. When the engine starts, the impulse mechanism is forced out of operating position, and the coupling acts as a solid connection between the engine drive and the magneto shaft.

Ignition-Type Overspeed Safety Devices

The overspeed safety devices discussed earlier in this course control the flow of either the fuel or the fuel-air mixture, depending upon the type of engine, to the cylinders. Some gasoline engines, however, are equipped with devices which function through the ignition system to prevent harmful overspeeding. Of the various ignition-type overspeed safety devices, two are described here: one as applied to a battery-ignition system; the other as used in connection with a magneto-ignition system.

BATTERY-IGNITION OVERSPEED GOVERNOR.—As used in a battery-ignition system, an overspeed safety device is sometimes called an overspeed governor. One type of overspeed governor, consisting of a tachometer and a relay, is set so as to open the ignition circuit at a speed just above the maximum rpm of the engine under full load. This arrangement permits the use of the full power of the engine at maximum rpm, but causes the ignition circuit to open when engine speed goes slightly above the prescribed maximum. The device also functions to prevent overspeeding when the throttle is opened under no-load conditions, or when the engine loses its load

The TACHOMETER includes a set of contact points which remain open until the engine speed exceeds the prescribed maximum by a predetermined number of rpm. One contact point is mounted on a movable arm which

is set so that contact is made with the other (stationary) contact point when the engine reaches a certain speed. The contact points of the tachometer are connected to magnetically-operated contact points in the RELAY. When the engine overspeeds, the points in the tachometer close and allow current to pass through the coil in the relay. This current flow produces a magnetic field which acts to open the contact points in the relay. When the relay points open, the flow of current in the ignition circuit is interrupted and the cylinders stop firing. When the tachometer speed drops to a predetermined level, the tachometer contacts open. This stops the flow of current to the relay coil and the relay contacts again close, completing the ignition circuit and causing the cylinders to begin firing again. The opening and closing of the ignition circuit at high speeds results in a surging action in the engine's operation; however, this interrupting action keeps the engine from "running away" when no-load conditions occur.

MAGNETO-IGNITION OVERSPEED CUTOUT.—The manner in which an ignition-type overspeed safety device stops a magneto system from firing the cylinders differs from that in which a battery-ignition system stops the firing. This difference may be more readily understood if consideration is first given to the function of the ignition switches in the two types of ignition systems.

In a battery-ignition system, the contact points of the ignition switch must be closed if the system is to function. When the points are closed, the primary circuit is completed and the current flows through the primary winding, through the breaker assembly, and back to the battery through the ground. In its flow through the low-voltage circuit, the current induces high voltage in the secondary circuit to produce sparks in the cylinders and keep the engine operating. To stop the engine, the points of the switch are opened; this breaks the circuit and stops the flow of current. The opposite of this situation is true in a magneto-ignition system. The contact points of the

ignition switch are open when the system is functioning; when the contact points close, the engine stops.

In a magneto-ignition system, the primary circuit is actually a closed circuit at all times, except when it is opened by the breaker assembly. (See fig. 8–16.) Unless the primary circuit is grounded, the magneto will generate current and the engine will continue to operate, as long as the armature rotates. The switch in a magneto-ignition system is actually a part of the primary-ground circuit, therefore, not a device to open and close the primary circuit as it is in the battery system. One side of the ignition switch is connected to the primary circuit, between the breaker points and the primary winding; the other side of the switch is connected to the ground, as illustrated in figure 8–19.

When the points of the switch are open, the current generated by the rotating armature flows through the primary circuit and induces high voltage in the secondary circuit. When the engine is stopped by "turning off" the ignition, the points of the ignition switch are closed. When the points are closed, the primary current flows through the switch to the ground, and is not interrupted

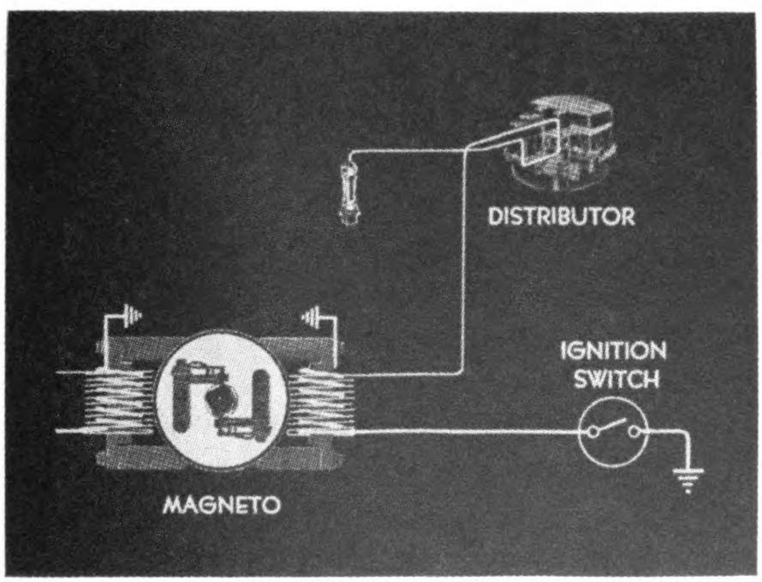


Figure 8–19.—Magneto-ignition system ground circuit.

by the points of the breaker assembly. Thus, no high voltage is induced and no sparks are produced at the plugs. The engine is stopped because the primary circuit is grounded rather than opened, as it would be in the battery-ignition system. Grounding the primary circuit of magneto-ignition system is also used to stop an engine which is overspeeding. One device used for this purpose is shown in figure 8–20.

The device illustrated is called an overspeed cutout. Driven by the camshaft, the cutout functions as a safety switch. It is connected in the magneto primary-ground circuit (see inset, fig. 8–20) and automatically grounds

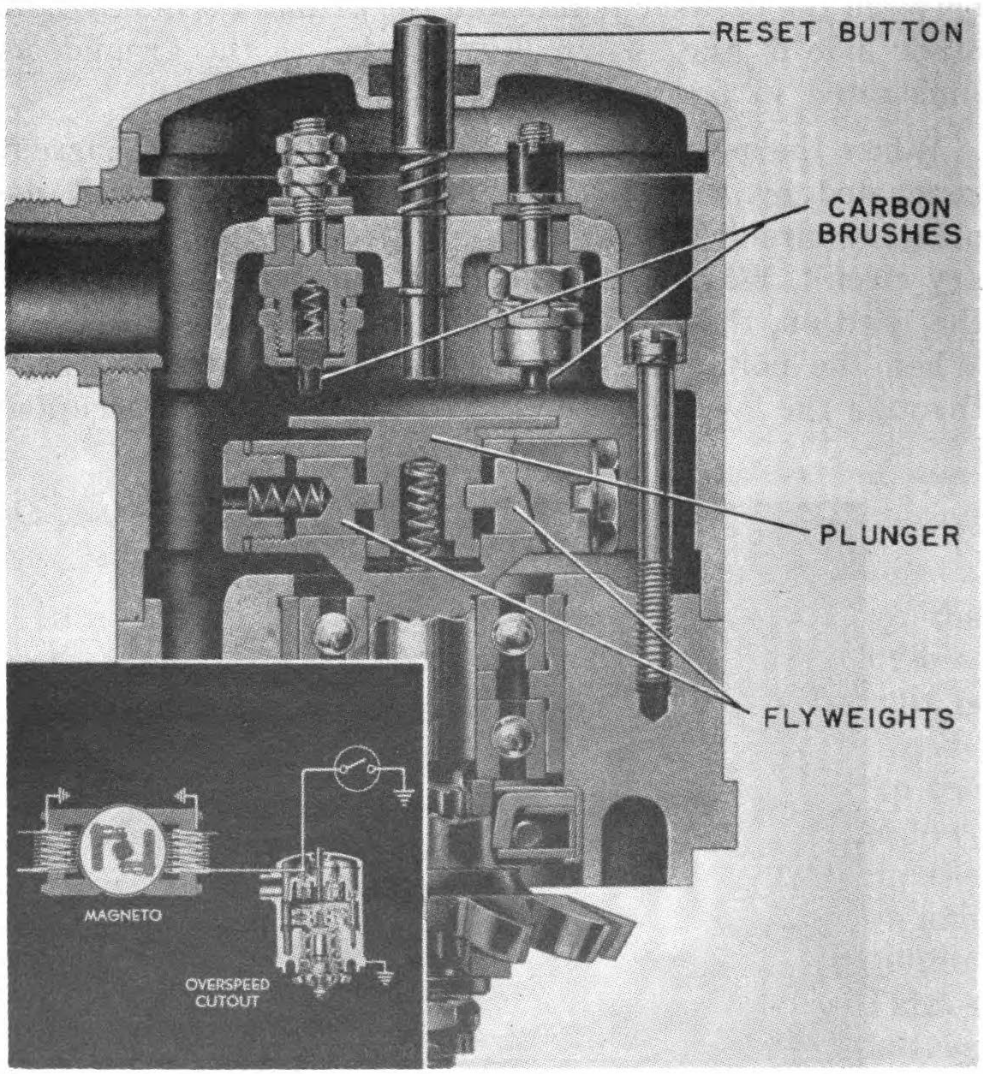


Figure 8–20.—Magneto-ignition system overspeed cutout.

the ignition system when the predetermined maximum engine speed is exceeded. The manner in which the cutout operates is illustrated in figure 8–21.

The overspeed cutout illustrated consists principally of a flyweight-and-plunger assembly at the top of the cutout shaft. The two FLYWEIGHTS have tongue ends, which are held in slots in the plunger by springs. As long as the engine is operating at a speed below the setting of the cutout, the ends of the weights remain in

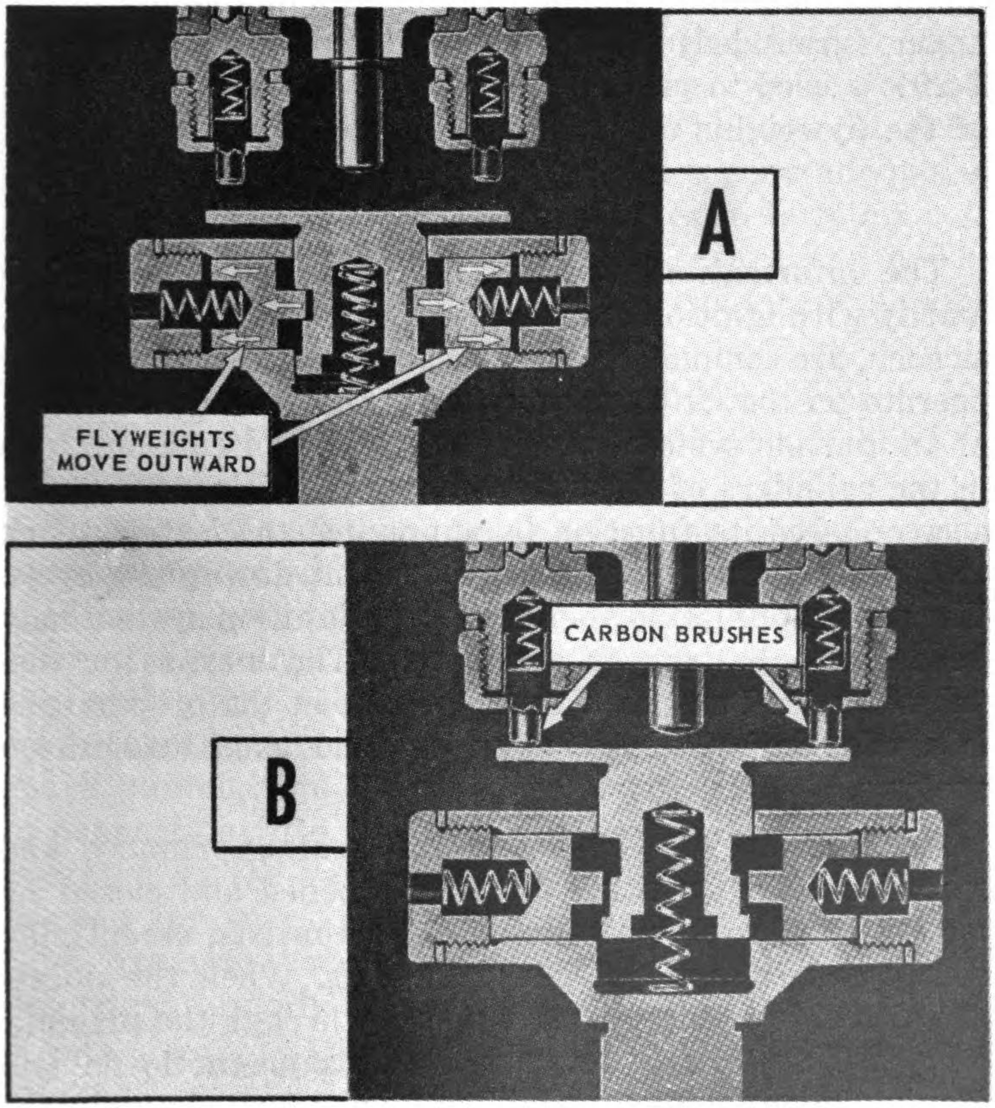


Figure 8–21.—Operation of an overspeed cutout.

the PLUNGER slots. (See fig. 8–20.) As the engine speed increases, the cutout shaft turns more rapidly and the increasing centrifugal force moves the two weights outward against the tension of the springs (*A*, fig. 8–21). When the engine speed exceeds that for which the cutout is set, the weights are moved completely out of the plunger slots and the released plunger is forced upward by a spring. The plunger is forced upward until it makes contact with two carbon brushes (*B*, fig. 8–21). When this contact is made, the primary circuit is grounded and the flow of current through the breaker assembly ceases; thus, the engine stops. The plunger will remain in the upper (grounded) position until the "reset" button (fig. 8–20) is used to push the plunger down so that the ends of the flyweights again engage the plunger slots.

SUMMARY

The information provided in this chapter deals primarily with ignition in gasoline engines. Ignition systems, as such, are commonly associated only with engines which operate on the Otto cycle. In brief, the primary function of an ignition system is to ignite the combustible mixture in the cylinders of a gasoline engine. An ignition system accomplishes its function by supplying an electric spark to each cylinder at the proper moment during the cycle. The source of electrical energy in an ignition system may be either a battery or a magneto. The means for distributing the current to each cylinder at the proper time is similar in both battery-ignition and magneto-ignition systems.

An ignition system has two circuits, primary and secondary. The primary circuit is opened and closed by means of a breaker assembly which consists, essentially, of a cam and a set of contact points. When the points are closed, low-voltage current flows through the primary circuit. This flow of current causes a magnetic field to develop in an ignition coil. The coil consists of a primary winding and a secondary winding.

When the points of the breaker assembly open, the current tends to continue to flow in the primary circuit and will jump the gap formed by the opening points unless a means is provided to stop the current flow. If the current jumps, or arcs, across the gap, the energy stored in the ignition coil cannot be fully utilized. A condenser is connected across breaker-assembly points to prevent this arcing. The condenser momentarily absorbs the current and brings the current flow to a quick, controlled stop. When the current flow stops, the magnetic field around the coil quickly collapses; and a high voltage is induced in the secondary winding, simultaneously. The high voltage causes a current flow from the secondary winding to the distributing mechanism, which consists principally of a rotor and a cap. The current flows through the rotor, the outer end of which generally passes close to terminal contacts in the cap. Each terminal contact is connected to a spark plug by a separate wire. The system is timed so that high-voltage current is induced at the instant the rotor is in line with a terminal contact in the cap. The current flows from the rotor to the terminal contact, and proceeds to the proper cylinder in firing-order sequence.

The time at which the spark occurs in a cylinder must vary according to engine speed; and, in some cases, according to load, if maximum power is to be obtained from the combustible mixture. Where engine speed is the controlling factor, the ignition system includes a centrifugal mechanism which controls the timing of the spark automatically. If load is a factor to be considered in connection with the timing of the spark, a mechanism operated by the varying vacuum in the intake manifold is used for spark control. In many cases units of both types are used in combination to vary timing of the spark according to both speed and load.

The battery-ignition system produces a spark of high intensity at engine cranking speed. On the other hand, the spark produced by a magneto at cranking speed is

too weak on many engines to properly ignite the combustible mixture. In order that a strong spark will be available at low cranking speeds, high-voltage current is ensured either by the use of a booster coil-and-battery circuit or by increasing magneto speed with an impulse mechanism.

QUIZ

1. What is the basic difference between the two common types of spark-ignition systems?
2. What is the primary purpose of the battery in a spark-ignition system?
3. What is the purpose of the shell of laminated iron that usually encloses the windings of an ignition coil?
4. What is the basis for sometimes calling the ignition coil of a battery-ignition system an induction coil?
5. What is the purpose of the breaker assembly in an ignition system?
6. In what two ways may the two-coil, double-breaker assembly arrangement be used in an ignition system?
7. What happens to the voltage in the primary circuit of an ignition system when a high voltage is induced in the secondary winding of an ignition coil?
8. What part of an ignition system functions to prevent arcing across the breaker-assembly points as they open?
9. What are the two principal parts of an ignition system distributing mechanism?
10. What is the function of the rotating part of a distributing mechanism?
11. Why are the distributor rotor and the breaker-assembly cam driven at one-half engine speed?
12. What causes the points of a breaker assembly to open and close?
13. If the breaker assembly is moved a few degrees in a direction opposite to the direction of cam rotation, is the time of spark occurrence, with respect to piston position, retarded or advanced?
14. If the time of spark occurrence is changed by moving the breaker-assembly cam, will moving the cam in a direction opposite to the direction of rotation retard or advance the spark?
15. What forces are utilized to operate automatic spark-control devices so that the time of spark is advanced?

16. When engine speed decreases, what causes an automatic spark-control mechanism to retard the spark?
17. What type of automatic control mechanism is used when variations in the timing of the spark are governed by engine speed?
18. Why are centrifugal and vacuum-type spark-control mechanisms sometimes used in combination?
19. The force which causes a distributor to move from the retarded position is transmitted from what part in a vacuum spark-control mechanism?
20. When a vacuum spark-control mechanism is in the retarded position, will the opening of the passage to the control unit be on the carburetor side or the manifold side of the throttle valve?
21. What is the principal difference between the two common types of spark plugs?
22. What determines the extent to which a spark plug will dissipate heat?
23. How do the metal housings or braided metal casings sometimes used to enclose the components of an ignition system prevent electrical interference in radio receiving equipment?
24. On the basis of the manner in which electromagnetic induction may be produced in a magneto, what are the two types of magnetos?
25. Is a separate ignition coil necessary with a magneto which generates high voltage?
26. Is the distributing mechanism of a low-voltage magneto-ignition system located in the primary circuit or in the secondary circuit?
27. With respect to circuits, how does the location of the distributing mechanism in a low-voltage magneto-ignition system differ from the location of this mechanism in other types of ignition systems?
28. List three advantages which a low-voltage magneto-ignition system has over a magneto system of the high-voltage type.
29. If a magneto does not generate the high voltage required for ignition when an engine is being started, how is the necessary voltage obtained during the cranking interval?
30. Does the current from the booster coil flow through the magneto?
31. What is the difference in the manner by which ignition-overspeed safety devices function to control speed in battery-ignition and magneto-ignition systems?

CHAPTER 9

ENGINE LUBRICANTS

Lubrication and the systems which supply lubricants to engine parts that involve sliding or rolling contact are as important to successful engine operation as air, fuel, and heat are to combustion. Lubrication is frequently considered one of the most important factors in efficient engine operation. Consequently, too much emphasis cannot be placed upon the importance of the engine lubrication system and lubrication in general. It is important not only that the proper type of lubricant be used, but also that the lubricant be supplied to the engine parts in the proper quantities, at the proper temperature, and that provisions be made to remove any impurities which enter the system. Before the description of the engine system which fulfills the above requirements, consideration will be given the characteristics and care of engine lubricants.

It is essential to the operation of an engine that the contacting surfaces of all moving parts of an engine be kept free from abrasion and that there be a minimum of friction and wear. If sliding contact is made by two dry metal surfaces under pressure, excessive friction, heat, and wear result. Friction, heat, and wear can be greatly reduced if metal-to-metal contact is prevented by keeping a clean film of lubricant between the metal surfaces. Both oils and greases are used in an engine to provide the necessary film between bearing surfaces.

If metal-to-metal contact is to be prevented and the other functions of the oil are to be performed, an engine lubricating oil must meet several requirements.

Requirements of Engine Oil

An oil must have certain characteristics and properties if the functions of engine lubrication are to be performed properly. An oil with the necessary properties and characteristics will: (1) provide a film of proper thickness between the bearing surfaces, under all conditions of operation; (2) remain stable under changing temperature conditions; and (3) not corrode the metal surfaces. If the lubricating oil is to meet these requirements, it is essential that the engine temperature permitted during operation not exceed a specified limit.

Functions of Engine Oil

If the temperature of the engine is maintained within prescribed limits and the lubricating oil has the proper characteristics and properties, the oil used in an engine will perform four functions. In addition to preventing metal-to-metal contact, the oil will (1) form a seal between the piston rings and the cylinder wall, (2) aid in engine cooling, and (3) aid in keeping the inside of the engine free of sludge.

PREVENTION OF METAL-TO-METAL CONTACT.—A direct metal-to-metal moving contact has an action that is comparable to a filing action. This filing action is due to minute irregularities in the surfaces, and the severity of the action depends upon the finish of the surfaces and the force with which the surfaces are brought into contact, as well as on the relative hardness of the materials used. Lubricating oil fills the minute cavities in bearing surfaces and forms a film between the sliding surfaces, thereby preventing high friction losses, rapid wear of engine parts, and many other operating difficulties. Lack of a proper oil film results in seized, or "frozen," pistons; wiped bearings; and stuck piston rings.

FORMATION OF A SEAL.—The high pressure in the cylinder of an engine can cause blow-by of the gases, between the piston rings and the cylinder liner unless lubricating oil forms a seal between these parts. The lubricating oil not only forms a gas-tight seal between the rings and the cylinder wall, but also serves to reduce friction.

SERVING AS A COOLANT.—Lubricating oil assists in cooling the engine, by transferring or carrying away heat from localized "hot" spots in the engine. The principal parts from which oil absorbs heat are the bearings, the journal surfaces, and the pistons. In some engines, the oil carries the heat to the sump, where the heat is dissipated to the mass of oil. However, most modern internal combustion engines use a centralized pressure-feed lubrication system. This type of system incorporates an oil cooler or heat exchanger, in which the heat from the oil is transferred to the circulating water of the cooling system.

PREVENTION OF SLUDGE.—Almost any type of gummy or carbonaceous material which accumulates in engine oil is termed sludge. Most engine lubricating oils have some natural ability for preventing conditions which may cause sludge to form and for carrying sludge that does form in a finely suspended state until it is removed by filtering equipment. Chemicals are added to some oils to improve their ability to prevent and to remove sludge.

The formation of sludge is greatly reduced if the lubricating oil has the proper stability. Proper stability is essential if a strong oil film, or body of oil, is to be maintained under varying temperature conditions. Stability of the oil should be such that a proper oil film is maintained throughout the entire operating temperature range of the engine. Such a film will ensure sufficient oiliness, or film strength, between the piston and the cylinder wall so that partly-burned fuel and the exhaust gases cannot get by the piston rings to form sludge.

Various factors may tend to cause sludge to form in an

engine. Carbon from the combustion chambers or that caused by the evaporation of oil on a hot surface, such as the underside of a piston, will cause the formation of sludge. Gummy, partially-burned fuel which gets past the piston rings or an emulsion of lubricating oil and water which may enter the lubricating oil system will also tend to cause sludge.

Sludge in the lubricating oil system of an engine is harmful for several reasons. In addition to carbon and gummy material, sludge may contain abrasive-like ingredients, such as dust from the atmosphere; rust caused as a result of water condensation in the engine; and metallic particles resulting from wear of engine parts. Sludge in engine lubricating oil causes premature wear of parts and eventual breakdown of the engine. Sludge may clog the oil pump screen or collect at the end of the oil passage leading to a bearing and thereby prevent sufficient oil from reaching the parts to be lubricated. Sludge will coat the inside of the crankcase, act as insulation, blanket the heat inside the engine, raise the oil temperature, and induce oxidation. Sludge will accumulate on the underside of the pistons and prevents proper heat transfer, thereby raising piston temperatures. Sludge in lubricating oil also contributes to piston-ring sticking.

Properties and Characteristics of Engine Oil

As pointed out in chapter 7, lubricating oil is a product of the fractional distillation of crude petroleum. Modern refining methods produce lubricating oils which have the properties and characteristics necessary to meet the requirements for use in engines. Some of the properties and characteristics of an oil which must conform to Navy specifications are viscosity, pour point, amount of carbon residue, flash point, tendency to cause corrosion, amount of water and sediment, degree of acidity, extent of emulsion, oiliness or film strength, amount of ash content, amount of sulphur, and degree of detergency. These properties and characteristics are determined by various types

of laboratory tests. These tests give some indication of how an oil may perform, but an actual service test is the best method of determining the quality of new oil. Manufacturers have conducted service tests to determine which oil is best suited for each of the engines they design.

You probably have come in contact with some of the terms used to identify the various properties of an oil. For this reason, only a few of the more important properties of the lubricating oils used in engines are discussed in this training course. If you desire additional information on petroleum products, see *Fundamentals of Diesel Engines, U. S. Navy,* NavPers 16178–A.

VISCOSITY.—The oil property which is generally considered to be the most important is viscosity. This is because friction, wear, and oil consumption are all more or less dependent on viscosity. It is this characteristic that determines film thickness and the ability of the oil to resist being forced out of a bearing. The viscosity of an oil changes with temperature. Therefore, the viscosity of a selected oil should be based upon the operating temperatures of the part to be lubricated.

For practical purposes, viscosity is determined by noting the number of seconds required for a given quantity of oil at a specified temperature, to flow through a standard orifice. For light oils (oils of low viscosity) the viscosity is determined at 130° F; for heavier oils, it is determined at 210° F. The Saybolt-type viscosimeter with a Universal orifice is used for determining the viscosity of lubricating oils. The longer it takes an oil to flow through the orifice, at a specified temperature, the heavier or more viscous the oil is considered.

Temperature is not the only factor which must be considered in determining the proper viscosity of oil for a particular engine. Clearances, speed, and pressures are also important factors. Greater clearances always require an oil with higher viscosity. Greater speed necessitates an oil with lower viscosity. Greater load necessitates higher viscosity in the oil. Therefore, the best oil for a

specific engine is a compromise between a high- and a low-viscosity oil.

Most high-speed engines run better when using low-viscosity oils, but the viscosity must not be so low that the oil film is too thin for efficient lubrication. On the other hand, oil with a viscosity greater than necessary should not be used; an oil with too great a viscosity increases starting friction. Increased friction raises oil temperatures and thereby promotes oxidation. In addition, an oil with too great a viscosity places an overload on the lubricating pump. This may result in an inadequate supply of oil reaching some moving parts.

CARBON RESIDUE AND DETERGENCY.—The carbon left after the volatile matter in a lubricating oil has been evaporated is known as the carbon residue of an oil. The carbon-residue test of an oil gives an indication of the amount of carbon that may be deposited in an engine by that oil. Excessive carbon in an engine leads to operating difficulties. The ability of an oil to remove or to prevent accumulation of carbon deposits is known as the detergent power, or detergency, of the oil.

FILM STRENGTH.—The ability of a lubricating oil to maintain lubrication between sliding or rolling surfaces under pressure and at local areas of high temperature is known as the film strength of the oil. Film strength is the result of several oil properties, the most important of which is viscosity.

Classification and Identification of Engine Oil

The lubricating oils approved by the Bureau of Ships for use in marine engines are divided into several SERIES or classes. Each series and each oil within the series is identified by a SYMBOL NUMBER.

MILITARY OIL SYMBOLS.—The numbers assigned to oils used by the Navy allow for ready identification of the oils, as to use and viscosity. Generally, each number consists of four digits; a letter suffix may be used to further identify an oil. The first digit of the number classifies the oil according to use; the last three digits indicate the oil's

viscosity. For example, the symbol 9110 describes an oil of the 9000 series (a compounded or additive-type heavy duty oil) which has a viscosity of 110 seconds, Saybolt Universal, when the oil is heated to 130° F.

OIL SERIES.—There are nine series, or classes, of Navy lubricating oils; however, only four of these series are used in internal combustion engines. The accompanying table lists the four oil series commonly used in internal combustion engines and provides examples of Military symbols along with equivalent SAE numbers.

ENGINE LUBRICATING OILS

Series	Classification	Examples of Military Symbols	SAE Equivalent
1000	Aviation oils	1080 1100 1120	40 50 60
2000	Forced-feed oils (Viscosity measured at 130°F.).	2190 2250	30 30
3000	Forced-feed oils (Viscosity measured at 210°F.).	3050 3065 3080 3100	20 30 40 50
9000	Compounded or additive-type heavy duty lubricating oils (Viscosity measured at 130°F, except 9500 which is measured at 210°F.).	9170 9250 9500	20 30 50

Oils of the 9000 series are used extensively in Diesel engines and in many gasoline engines. Some gasoline engines use oils of the 2000 or 3000 series corresponding to the SAE number recommended by the engine manufacturer for a given operating condition. Outboard-motor

type gasoline engines use a 3000 series oil. The Packard gasoline engine used in PT craft uses oil of the 1000 series.

Oils in the four series shown in the table are of two general types: the mineral type and the compounded, or additive, type. Engine oils in the 1000, 2000, and 3000 series are of the mineral type. Oils in the 9000 series are of the compounded type. You will probably encounter oils of the compounded type more frequently; they are now used extensively for crankcase lubrication in both gasoline and Diesel engines and for general-purpose lubrication.

Additive Engine Oils

Compounded or additive-type lubricating oils, sometimes called detergent oils, consist of a base mineral oil to which chemical additives have been added. The performance of the base lubricant is improved by the additives, which inhibit oxidation, improve the natural detergent property of the oil, and improve the tendency of the oil to adhere to metal surfaces.

In modern internal combustion engines, the lubricating oil used must have both detergency and resistance to oxidation to give satisfactory operation with respect to engine wear, engine cleanliness, and oil life. The Military symbol 9000 series lubricating oils have been developed to meet these requirements. Developed primarily for the lubrication of high-speed, high-output Diesel engines, these additive-type oils are now used in most internal combustion engines. The use of additive-type oils reduces bearing wear and corrosion and minimizes the formation of carbon and gummy deposits throughout the lubrication system and on the piston rings. There are a number of factors related to the use of additive oils which should be kept in mind when you are operating and maintaining an engine.

MIXING POSSIBILITIES.—All Navy-approved engine oils

may be mixed without harmful effects. To obtain the maximum benefit from additive-type oils, however, do not mix them with straight mineral oils, except in emergencies. Mixing of the two types of oil will greatly reduce the additive concentration. Nevertheless, a mixture of additive-type and mineral oils will provide better lubrication than straight mineral oil in places where a detergent oil is recommended. When mixing oils of two different viscosities, remember that the viscosity of the mixture will be different from that of either oil.

NONCORROSION CHARACTERISTICS AND CORROSION.—Lubricating oils of the 9000 series are noncorrosive to all types of alloy bearings and all metals used in an engine. If bearing surfaces are found to be corroded, it is likely that the oil has been contaminated either with water or with partially burned fuel. When corrosion is found in an engine, steps must be taken to eliminate the source of trouble. It is important that fuel systems be kept in good repair and adjustment at all times. Every precaution possible should be taken to prevent the entrance of an appreciable quantity of water into the lubricating system.

The presence of water in lubricating oil can usually be detected by the cloudy appearance of the oil and by the presence of small droplets of water in a sample shaken up in a bottle. Small quantities of water in fresh lubricating oil can usually be detected by the presence of a cloud of whitish color in the oil. A small quantity of fresh water in oil will cause no difficulty because it usually evaporates when the oil passes through the hot engine. However, where serious water contamination exists, the oil should be drained and replaced with fresh oil after the source of leak has been discovered and repaired.

CHANGES IN COLOR.—Detergent oils change color, normally turning dark after a few hours of use. The change in color is due to the suspension of fine particles of fuel soot which the oil accumulates. The change in color in no way indicates a reduction in the lubricating quality of the oil.

Purification of Lubricating Oil

In addition to being clean before it goes into the lubricating system of an engine, the oil must be cleaned or purified regularly while it is being recirculated through the engine. Dust and dirt particles from the intake air get into the oil system. Bits of metal from the engine parts are picked up and carried in the oil. Carbon particles from combustion in the cylinders work into the oil, even in the best engine. The oil itself deteriorates and leaves some sludge and gummy material which circulate through the oil system. Some water will get into the oil, even when precautions are taken to prevent this.

Contamination must be removed or the oil will not meet the requirements of lubrication. Dirt and other hard particles score and scratch the rubbing metal surfaces within the engine. This abrasive action greatly increases friction and heating of the moving parts, and causes them to wear faster. Sludge and water interfere with the ability of the oil to hold a good lubricating film between the rubbing surfaces within the engine.

Several devices are used to keep the oil as pure as possible. Each device is designed to remove certain kinds of contamination. It takes several types of devices in the lubricating oil system, therefore, to keep the oil in the best possible condition. Strainers, filters, settling tanks, and centrifugal purifiers are the main devices used to keep oil free of contamination. Strainers and filters are discussed in the next chapter, in connection with lubricating systems. Settling tanks and purifiers are considered in this chapter, with emphasis on purifiers.

The lubricating systems of many shipboard Diesel engine installations include settling tanks (used-oil tanks). These tanks are provided to allow the oil to stand while accumulated water and other impurities settle. Settling is due to the force of gravity. A number of layers of contamination may form, the number depending upon the different specific gravities of the various substances which

contaminate the oil. Settling takes place more rapidly and more efficiently when the oil is heated.

Even though settling tanks do much in the way of removing contamination from lubricating oil, most ships have additional equipment which functions to purify the oil by removing water and impurities not removed by other devices. The machines which perform the purification process are usually called purifiers; they are, however, frequently referred to as centrifuges.

Detailed instructions on the construction, operation, and maintenance of purifiers are furnished by the manufacturer with each machine. Such instructions should be carefully studied and followed when you are responsible for the operation and maintenance of a purifier. The following general information is provided to familiarize you with the methods of purification, and the purpose and principles of operation of purifiers.

METHODS OF PURIFICATION.—On Diesel-propelled vessels, the piping system is generally arranged to permit two methods of purifying: BATCH purification and CONTINUOUS purification.

In the batch process, the lubricating oil is transferred from the sump to a settling tank by means of a transfer pump. The oil is heated in the settling tank and its temperature is maintained at about 175° F for several hours by means of steam-heating coils. Water and other settled impurities are drained from the settling tank through a valve. The oil is then centrifuged and discharged back to the sump from which it was taken.

In the continuous purification process, the centrifugal purifier takes suction from a sump tank and, after purifying the oil, discharges back to the same sump. The continuous method of purification is generally used while a vessel is under way.

PRINCIPLES OF PURIFIER OPERATION.—Centrifugal force is utilized in the operation of purifiers. Centrifugal force is that force which is exerted upon a body or substance

by rotation; it impels the body or substance outward from the axis of rotation.

A centrifugal purifier is essentially a container which is rotated at high speeds while contaminated oil is forced through, and rotates with, the container. The centrifugal force imposed on the oil by the high rotating speed of the container acts to separate the suspended foreign matter from the oil. However, only materials that are insoluble in one another can be separated by centrifugal force. For example, gasoline or Diesel fuel cannot be separated from lubricating oil, nor can salt be removed from sea water by centrifugal force. Water, however, can be separated from oil because water and oil do not form a solution when mixed. Furthermore, it is necessary that there be a difference in specific gravity between the materials to be separated.

When a mixture of oil, water, and sediment stands undisturbed, the action of gravity tends to form an upper layer of oil, an intermediate layer of water, and a lower layer of sediment. The layers form because of the different specific gravities of the substances in the mixture. If the oil, water, and sediment are placed in a container which is revolving rapidly, around a vertical axis, the effect of gravity is negligible in comparison with that of the centrifugal force. Since centrifugal force acts at right angles to the axis of rotation of the container, the sediment, with its greater specific gravity, assumes the outermost position, forming a layer on the inner surface of the container. Water, being heavier than oil, forms an intermediate layer between the layer of sediment and the oil, which forms the innermost layer. Centrifugal purifiers are so designed that the separated water is discharged as waste and the oil is discharged for reuse. The solids remain in the rotating unit; the units are cleaned manually when necessary.

The effectiveness of separation by centrifugal force is further affected by the size of the particles, the viscosity of the fluids, and the time during which the materials are

subjected to the centrifugal force. In general, the greater the difference in specific gravity between the substances to be separated and the lower the viscosity of the oil, the greater will be the rate of separation.

USE OF PURIFIERS.—Centrifugal purifiers are used to purify both fuel oil and lubricating oil. A purifier may be used either to remove water and sediment from oil or to remove sediment only. When water is involved in the purification process, the purifier is usually called a SEPARATOR. When the principal item of contamination is sediment, the purifier is used as a CLARIFIER. Purifiers are generally used as separators when purifying fuel oils. When used to purify a lubricating oil, a purifier may be used as either a separator or a clarifier. Whether a purifier is used as a separator or a clarifier depends upon the moisture content of the oil being purified.

An oil which contains no moisture needs only to be clarified, since the oil will be discharged in a purified state after the solids deposit in the bowl of the purifier. If, however, the oil contains some moisture, the continued feeding of "wet" oil to the bowl results eventually in a bowl filled with water; from that time on the centrifuge is not accomplishing any separation of water from the oil. Even before the bowl is completely filled with water, the presence of a layer of water in the bowl reduces the depth of the oil layer. As a result, the incoming oil passes through the bowl at a very high velocity. Because of this, the liquid is subject to centrifugal force for a shorter time; the separation of water from the oil is, therefore, not so complete as it would be if the bowl were without the water layer, or if the water layer were a shallow one. For this reason the centrifuge should not be operated as a clarifier unless the oil contains little or no water. A small amount of water can be satisfactorily accumulated, together with the solids, to be drained out when the bowl is stopped for cleaning; if there is any appreciable amount of water in the oil, however, the purifier should be operated as a separator.

TYPES OF CENTRIFUGAL PURIFIERS.—There are two types of purifiers used in Navy installations. Both types operate on the same general principle. The principal difference between the two types of purifiers is in the design of the rotating units. In one type of purifier, the rotating element is a hollow tubular rotor; in the other type of purifier, the rotating element is a bowl-like container which encases a stack of disks. The two types are known as the tubular type purifier and the disk type purifier, respectively.

A sectional view of a DISK TYPE CENTRIFUGAL PURIFIER is shown in figure 9–1. The bowl is mounted on the upper end of the vertical bowl spindle, which is driven by means

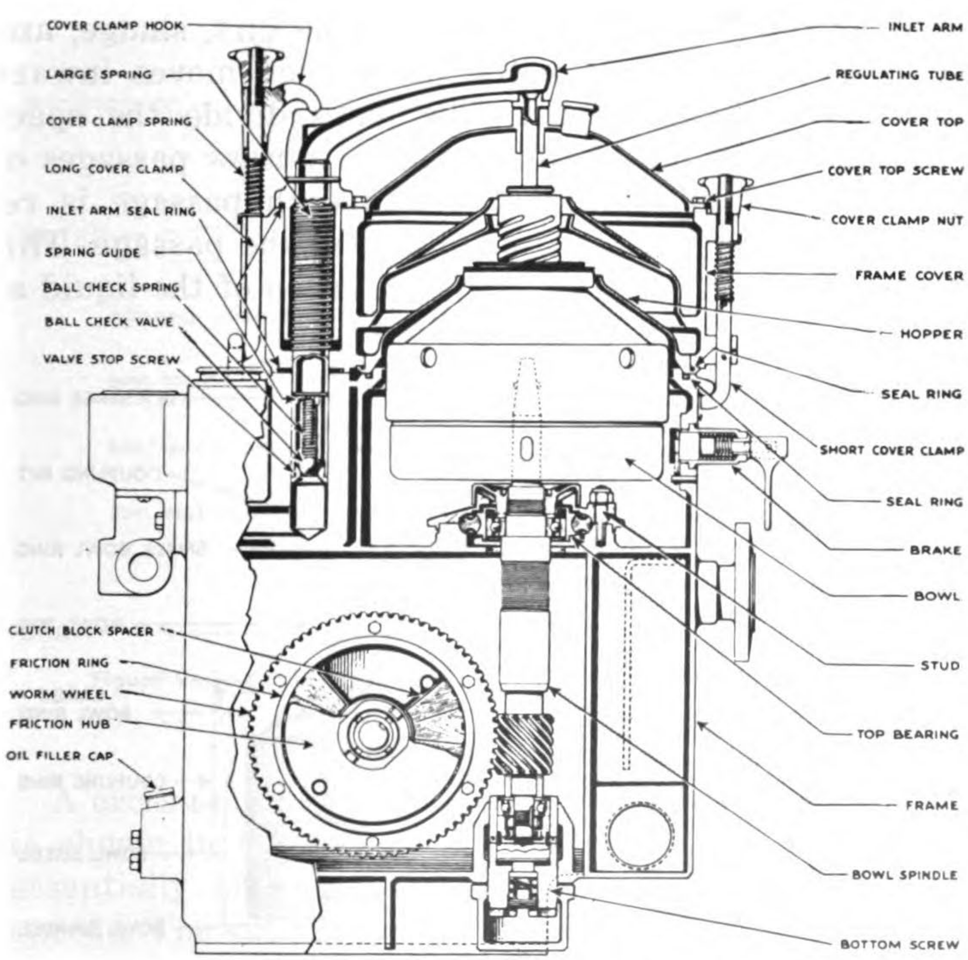


Figure 9–1.—Disk type centrifugal purifier (DeLaval).

of a worm wheel and a friction clutch assembly. A radial thrust bearing is provided at the lower end of the bowl spindle to carry the weight of the bowl spindle and to absorb any thrust created by the driving action. The flexible mount of the upper-spindle bearing allows the bowl to come to the center of rotation.

The parts of a disk type bowl are shown in figure 9–2. The flow of oil, through the bowl and additional parts, is shown in figure 9–3.

Contaminated oil enters the top of the revolving bowl through the regulating tube. The oil then passes down the inside of the tubular shaft and out, at the bottom, into the stack of disks. As the dirty oil flows up through the distribution holes in the disks, the high centrifugal force exerted by the revolving bowl causes the dirt, sludge, and water to move outward; the purified oil moves inward toward the tubular shaft. The disks divide the space within the bowl into many, separate, narrow passages or spaces. The liquid confined within each passage is restricted so that it can flow only along the passage. This arrangement prevents excessive agitation of the liquid as

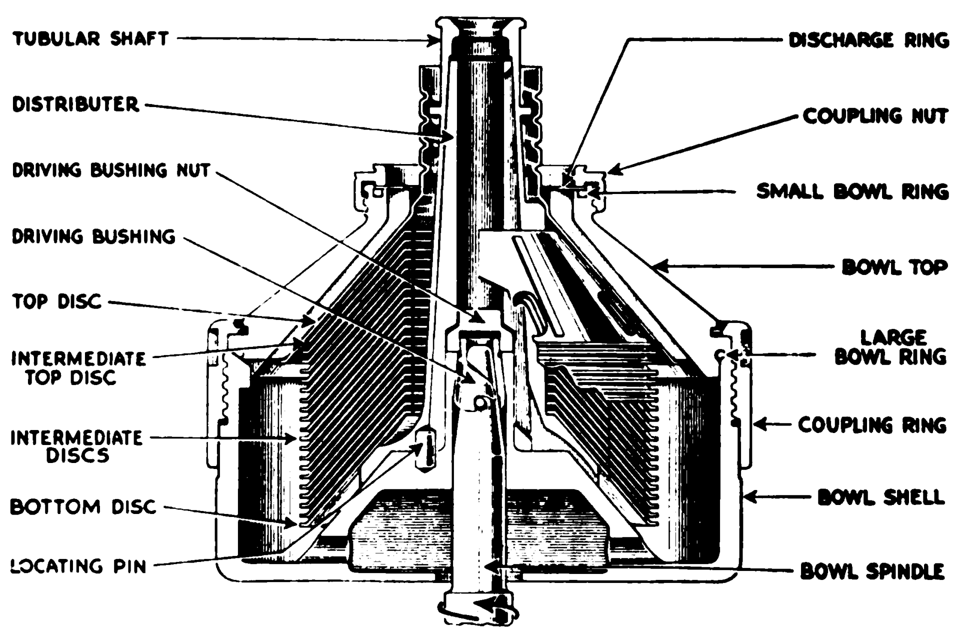


Figure 9–2.—Parts of a disk type purifier bowl (DeLaval).

it passes through the bowl, and creates shallow settling distances between the disks.

Most of the dirt and sludge remains in the bowl, collecting in a more or less uniform layer on the inside vertical surface of the bowl shell. Water, along with some dirt and sludge, separated from the oil, is discharged through the discharge ring at the top of the bowl. The purified oil flows inward and upward through the disks, discharging from the neck of the top disk. (See fig. 9–3.)

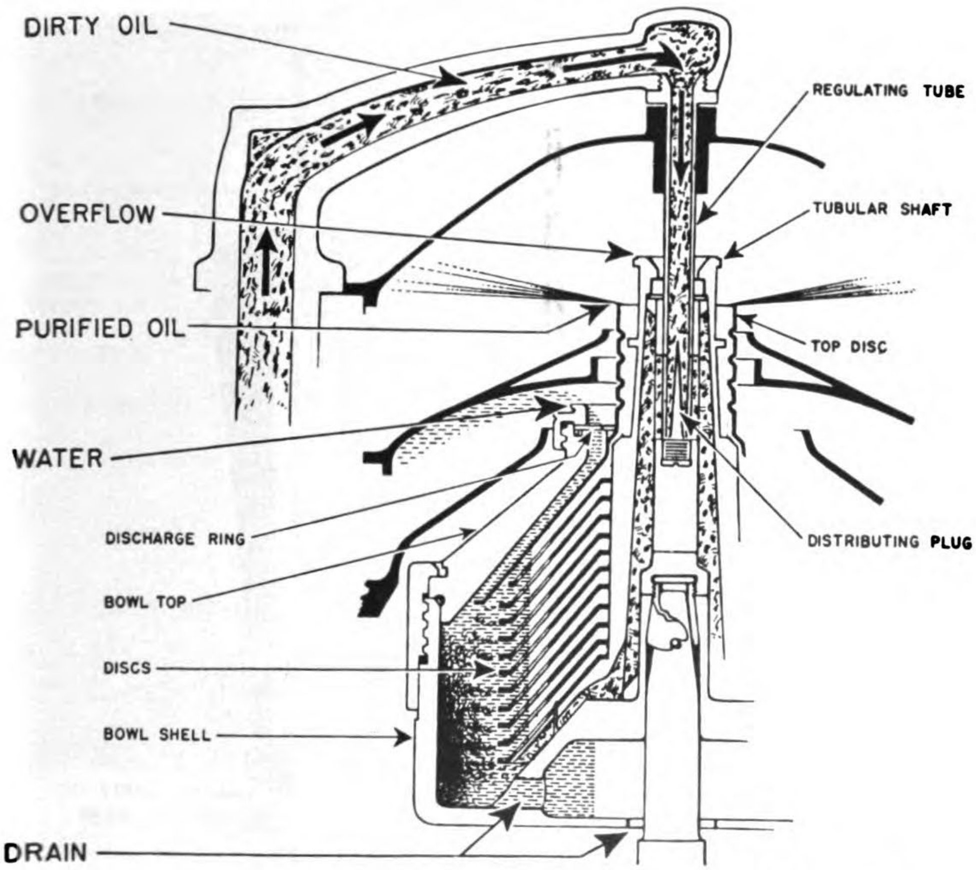


Figure 9–3.—Path of contaminated oil through a disk type purifier bowl (DeLaval).

A cross-section of a tubular type CENTRIFUGAL PURIFIER is shown in figure 9–4. A purifier of this type consists essentially of a rotor, or bowl, which rotates at high speeds. The rotor has an opening in the bottom through which the dirty lubricating oil enters, and two sets of openings in the bowl top through which the oil and water

(in a separator action) or the oil alone (in a clarifier action) discharge. (See inset, fig. 9–4.) The bowl, or hollow rotor, of the purifier is connected, by a coupling unit, to a spindle suspended from a small bearing assembly. The bowl is belt-driven by an electric motor mounted on the frame of the purifier.

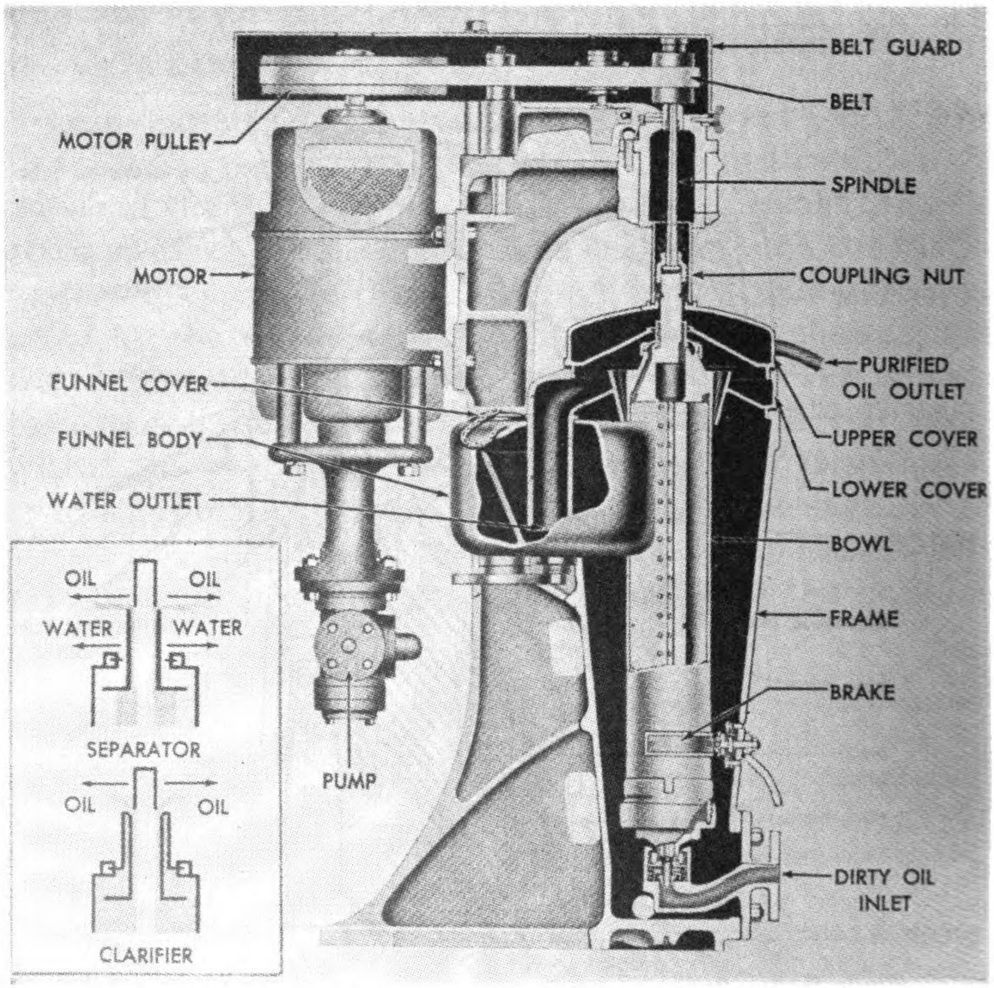


Figure 9–4.—Tubular type centrifugal purifier (Sharples).

The lower end of the bowl extends into a flexibly mounted drag bushing. The assembly of which this bushing is a part restrains movement of the bottom of the bowl; it allows sufficient movement, however, so that the bowl can center itself about its center of rotation, when the purifier is in operation. Inside the bowl is a device

consisting essentially of three flat plates which are equally spaced radially. This device is commonly referred to as the three-wing device, or just the three-wing. The three-wing rotates with the bowl; its purpose is to force the liquid in the bowl to rotate at the same speed as the bowl. The liquid to be centrifuged is fed into the bottom of the bowl, through the feed nozzle, under pressure so that the liquid jets into the bowl in a stream.

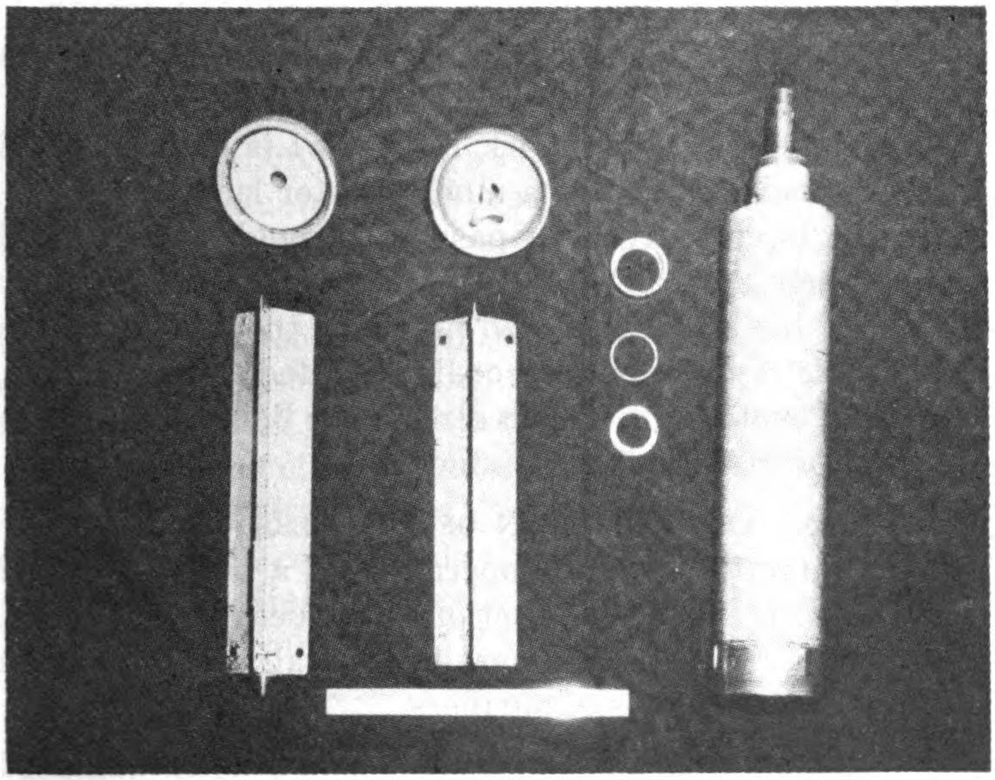


Figure 9–5.—Parts of a tubular type purifier bowl.

When the purifier is used as a lubricating oil clarifier, the feed jet strikes against a cone which is placed on the bottom of the three-wing; this brings the liquid up to bowl speed smoothly, without making an emulsion. This cone is not necessary when the purifier is used as a separator with fuel oil, because fuel does not have the tendency to emulsify. Both types of three-wing devices are shown in figure 9–5.

In the tubular type purifier, the process of separation is the same as in the disk type purifier. In both types of purifiers, the separated oil assumes the innermost position and the separated water moves outward. Both liquids are discharged separately from the bowls; solids separated from the liquid are retained in the bowls.

Even though similar in operation, the two types of purifiers differ somewhat in design features. By comparison, the bowl of a tubular type purifier is of small diameter and is operated at a high speed. The length of the tubular bowl (the distance the liquid travels through the bowl) is many times the depth of the liquid layer (settling distance). The disk type bowl is characterized by a larger diameter and a much shorter length; the distance the liquid travels in passing through such a bowl is not much greater than the settling distance. Tubular bowls are fed through a feed nozzle at the bottom of the bowl. Disk type bowls are ordinarily fed from the top, through a center tube which directs the liquid toward the distribution holes in the disk stack.

NOTES ON THE OPERATION OF PURIFIERS (GENERAL).—Specific directions for the operation of a purifier should be obtained from the instructions provided with the unit. The information provided here is general, and applies, in the main, to both types of purifiers.

For maximum efficiency, purifiers are to be operated at their maximum designed speed and rated CAPACITY. An exception to operating a purifier at designed rated capacity is made when the unit is used as a separator with 9000 series detergent oil. Some engine installations using oils of the 9000 series are exposed to large quantities of water. When the oil becomes contaminated with water, the oil has a tendency to emulsify. This tendency to emulsify is most pronounced when the oil is new, and gradually decreases during the first 50 to 75 hours of engine operation. During this period, the purifier capacity

should be reduced to approximately 80 percent of the rated capacity.

When a purifier is operated as a separator, PRIMING OF THE BOWL with fresh water before any oil is admitted to the purifier is essential. The water serves to seal the bowl and to create an initial equilibrium of liquid layers. If the bowl is not primed, the oil will be lost through the water discharge ports.

There are several FACTORS WHICH INFLUENCE PURIFIER OPERATION. The time required for purification and the output of a purifier depend upon such factors as the viscosity of the oil, the pressure applied to the oil, the size of the particles of sediment, the difference between the specific gravity of the oil and that of the substances which contaminate the oil, and the tendency of the oil to emulsify.

The viscosity of the oil determines, to a great extent, the length of time required for purification of lubricating oil. The more viscous the oil, the longer the time required to purify it to a given degree of purity. Decreasing the viscosity of the oil by heating is one of the most effective methods of facilitating purification.

Even though certain oils may be satisfactorily purified at operating temperatures, a greater degree of purification will generally result if the oil is heated to a higher temperature. To accomplish this, the oil is passed through a heater where the desired temperature is obtained before the oil enters the purifier bowl.

Most oils used in Navy installations may be heated to a temperature of 180° F without injury. Prolonged heating at higher temperatures is not recommended because of the tendency of such oils to oxidize at high temperatures. Oxidation results in rapid deterioration. In general, oil should be heated sufficiently to produce a viscosity of approximately 90 seconds, Saybolt Universal (90 SSU), but the temperature should not exceed 180° F. The temperatures recommended for purifying oils in the 9000 series are shown in the table on page 332.

Military Symbol	*Temperature (°F)*
9110	140
9170	160
9250	175
9370	180
9500	180

Pressure should not be increased above normal in order to force a high-viscosity oil through the purifier. Instead, the viscosity should be decreased by heating the oil. The use of pressure in excess of that normally used to force oil through the purifier will result in less efficient purification. On the other hand, a reduction in the pressure at which the oil is forced into the purifier will increase the length of time the oil is under the influence of centrifugal force, and therefore will tend to improve results.

If the oil discharged from a purifier is to be free of water, dirt, and sludge, and if the water discharged from the bowl is not to be mixed with oil, the PROPER SIZE DISCHARGE RING (RING DAM) must be used. The size of the discharge ring to be used depends on the specific gravity of the oil being purified. While all discharge rings have the same outside diameter, their inside diameters vary. Ring sizes are indicated by even numbers; the smaller the number, the smaller the ring size. The inside diameter, in millimeters, is stamped on each ring. Sizes vary by two-millimeter steps. Charts, provided in instruction manuals, specify the proper size ring to be used with an oil of a given specific gravity. Generally, the ring size indicated on such a chart will produce satisfactory results. However, if the recommended ring fails to produce satisfactory purification, it will be necessary to determine the correct size by trial-and-error. In general, the most satisfactory purification of the oil is obtained when the ring is of the largest size which can be used without loss of oil with the discharged water.

MAINTENANCE OF PURIFIERS.—The bowl of a purifier must be cleaned frequently; all sediment must be care-

fully removed. The frequency of cleaning depends upon the amount of dirt, grit, sludge, and other foreign matter in the oil being purified. If the amount of foreign matter in an oil is not known, the machine should be shut down for examination and cleaning once each watch, or more often if the condition of the system indicates that more frequent cleanings are necessary. The amount of sediment found in the bowl will give an indication as to how long the purifier may be operated between cleanings.

Periodic tests should be made to ensure that the purifier is working properly. When the oil in the system is being purified by the batch process, tests should be made at intervals of about 30 minutes. When the continuous process of purification is used, tests should be made once a watch. Analysis of oil drawn from the purifier is the best method of determining the efficiency of the purifier; however, the clarity of the purified oil and the amount of oil discharged with the separated water will also indicate whether or not the unit is operating satisfactorily.

GREASES

While oil is the primary lubricant used in engines, you should be familiar with greases, also. They are used in certain places where oil will not provide proper lubrication. Operating temperatures, the rate at which lubrication must be supplied, and the design of the equipment may make the use of oil impractical. At points where oil will not provide proper lubrication, engine manufacturers have provided fittings of the pressure type or the cup type, by means of which a grease of the proper type and grade is to be applied. The location of grease fittings and the type of grease required are shown on engine lubrication charts and in instruction manuals. It is important that you follow lubrication instructions, since some greases are of the type developed for general use and others are developed for special purposes. Maintenance problems involving lubrication will be more readily understood if you are familiar with the principal factors related to the composition, classification, and storage of greases.

Composition and Types of Grease

Lubricating greases are made of soaps and lubricating oils. The soaps are chemical compounds which are formed by the reaction of fats or fatty acids and various alkaline materials such as lime, soda, and aluminum. The most common greases which have been found adequate for all ordinary types of service are those made with either a lime soap or a soda soap. Lime-soap greases do not absorb moisture (emulsify) as readily as soda-soap greases; however, they have lower melting points. For these reasons, lime-soap greases are recommended as GENERAL PURPOSE GREASES in situations where moisture is a factor and ordinary operating temperatures and light loads are involved. Soda-soap greases are recommended for applications where no water is present and where operating temperatures approach 200° F. Even though lime-soap greases and soda-soap greases will provide adequate lubrication for a majority of applications, there are certain applications which require special characteristics in greases. SPECIAL GREASES are not generally used in engine lubrication; they are included here, however, since some of the machines which you will operate and maintain may require such greases.

In some machines, certain bearing surfaces are so heavily loaded that the ordinary lime greases and soda greases will not provide a film adequate to prevent contact of the surfaces. Greases which will provide the necessary film strength for heavy loads have been developed by incorporating additive agents in lime-soap greases and soda-soap greases. Greases of this special type are commonly known as extreme pressure (E.P.) lubricants.

Another type of special lubricant includes those greases which contain graphite. In graphite greases, the graphite acts as a mild abrasive to smooth rough bearing surfaces and as a filler of small irregularities in the bearing surfaces. Because of a low-friction characteristic, graphite grease is useful where a bearing is exposed to temperatures sufficiently high to destroy ordinary grease or oil.

Except where extremely high temperatures exist, graphite grease should not be used in bearings that are in first-class condition. Because of the abrasive characteristic of graphite greases, they should never be used to lubricate ball bearing or roller bearing assemblies.

Examples of Classification and Identification of Greases

In general, greases are classified according to type and grade. The classification of a grease is based upon its composition, the use for which it is intended, the temperature at which proper lubrication is provided, and whether or not the grease is water resistant. Greases are identified, by symbols, according to type or grade or a combination of both. Examples of identifying designations and general information on a few of the greases you will use are given in the following paragraphs.

GENERAL PURPOSE LUBRICANT, Type A, Grade I.—Lubricants in this classification may be of lime-, soda-, or aluminum-soap base. The lime- and aluminum-soap base types are water resistant. A type A, Grade I grease is for general use as a cup or a pressure lubricant and for use with ball-bearings, particularly where the operating temperature of the unit being lubricated is below 150° F.

GENERAL PURPOSE LUBRICANT, No. 2, Type A, Grade II.—These greases have a soda- or a mixed-soap base and are not water resistant. Type A, Grade II greases are used for purposes similar to those for which Type A, Grade I greases are used; Type A, Grade II greases are used, however, where operating temperatures are expected to exceed 150° F.

CHAIN AND WIRE-ROPE LUBRICANT.—Supplied in one grade, this lubricant is used for greasing cable, open gears, and any other open mechanism in which rough lubrication is adequate. The lubricant consists of a sticky, viscous, black, residual oil and is usually heated before application. The lubricant is suitable for open-air and under-water applications.

WATER-PUMP LUBRICANT, No. 4, Type A, Grade IV.—These greases have a lime-soap base and are highly water resistant. Greases in this class have been developed for the lubrication of gland-type water pumps of gasoline and Diesel engines which are not equipped with factory-lubricated, sealed pumps.

BALL BEARING AND ROLLER BEARING LUBRICANT, Navy Type.—Greases in this group have either a soda- or a mixed-soap base. Ball bearing and roller bearing lubricant cannot be satisfactorily used where it comes in direct contact with water; the lubricant will emulsify and "wash out" of the bearing.

Greases may also be classified, or graded, as SOFT, MEDIUM, and HARD greases. In general, soft greases are used with light pressures and high speeds; medium greases are used with medium pressures and medium speeds; and hard greases are used with heavy pressures and slow speeds. Type A lubricants of Grades I, II, and IV are soft, medium, and hard, respectively.

Storage and Handling of Grease

All lubricants tend to deteriorate through chemical combination with oxygen. This process is generally called oxidation. The speed at which oxidation takes place is increased at high temperatures. Some greases become useless at temperatures above 195° F. Therefore, it is essential that lubricants be stored in relatively cool spaces; they must never be stored close to sources of heat.

Generally, greases may be applied easily at temperatures as low as 45° F. When extremely low temperatures cause greases to become too stiff for proper application, the greases should be placed in a warm space and their temperature gradually raised to approximately 70° F. Never apply intense heat directly to the surface of a lubricant container.

Foreign particles which contaminate oil will generally settle out. This is not true in the case of grease. Rather, any particles of foreign matter which contaminate a

grease will remain suspended in the grease. Since it is likely that foreign matter in grease may act as an abrasive, particular care must be taken to prevent such contamination of greases.

All dirt must be removed from the exterior of a grease container before the container is opened. The equipment used for applying and handling grease must be kept free of any foreign matter which may cause abrasive action or corrosion. Pressure fittings must be wiped clean before the gun is applied; particular care must be taken to prevent dirt from entering grease cups while they are being filled.

SUMMARY

In an engine, lubricating oil functions to reduce friction, aid in sealing the combustion space, cool engine parts, and reduce sludge formation. If the functions of lubrication are to be performed properly by an oil, its properties and characteristics must be such that an oil film of the proper thickness and strength is provided, at all operating temperatures, between bearing surfaces; and that carbon residue is either prevented from forming or removed as it forms.

Of the nine classes of Navy-approved oils, four are used as engine lubricants. The viscosity and use of each oil within a series is identified by a symbol number. A lubricating oil may be either a mineral or a compounded type lubricant. Compounded oils contain chemical additives which improve the qualities of the lubricant.

As an EN3, one of your primary responsibilities is to maintain engine lubricating oil in as pure a state as possible. This means that you must not only take every precaution possible to keep contamination from entering the oil but also know how to operate and maintain the equipment which is used to purify contaminated oil. Settling tanks and purifiers are used to remove contamination from lubricating oil. In settling tanks, gravitational force causes most of the impurities to settle out and thereby separate from the oil. Separation takes place because

practically all impurities are heavier than the oil which they contaminate. Purification, faster and more efficient than separation by settling, is obtained by the use of purifiers, which utilize centrifugal force to separate impurities from the oil.

Greases are used for lubrication where operating conditions and design of equipment make the use of oil impractical. Some greases are developed for general purpose use; others are made for special applications. The classification of a grease is based upon its composition, resistance to water, the intended use, and the temperature at which proper lubrication is provided. A grease may also be classified as soft, medium, or hard.

The speed at which a lubricant oxidizes is increased as temperature increases. For this reason, it is essential that precautions be taken to prevent exposing lubricants to unnecessarily high temperatures when the lubricants are being stored or handled.

You will be better qualified to meet the qualifications for advancement if you are familiar with the requirements, the properties and characteristics, and the classification and identification of engine lubricants. Knowing what is expected of an engine lubricant and how to keep oil free of contamination will aid you in keeping an engine in the best operating condition. If you have a thorough knowledge of engine lubricants and of the factors related to lubrication, operation and maintenance problems will be easier to understand. Systems which supply lubricants to engine parts are discussed in the next chapter.

QUIZ

1. Name four functions of an engine lubricating oil.
2. How does lubricating oil reduce friction between bearing surfaces?
3. In addition to reducing friction, why is an oil seal necessary between the piston rings and the cylinder wall?
4. What are the principal engine parts which lubricating oil may cool?
5. With respect to the engine, where may the heat absorbed by lubricating oil be dissipated?
6. The thickness of the oil film between two bearing surfaces is determined principally by which property of the oil?
7. What characteristics of an engine determine the viscosity of the lubricating oil to be used?
8. What is meant by the detergent power of an oil?
9. What is the purpose of the symbol numbers assigned to Navy oils?
10. How are the lubricating qualities of an oil improved by chemical additives?
11. If the recommended compounded oil is not available in sufficient quantities, would it be better to use a straight mineral oil or a mixture of additive- and mineral-type oils?
12. What is the most likely source of trouble if corrosion is found on the internal surfaces of an engine which uses compounded oil?
13. Does the suspension of fine particles of gummy material and carbon in an additive-type oil indicate a reduction in the lubricating quality of the oil?
14. In a centrifugal purifier, what causes sediment, water, and oil to form separate layers?
15. In brief, what is the purification process when a purifier is used as a separator? As a clarifier?
16. What determines whether a purifier should be used as a separator or as a clarifier?
17. Is the principle of operation or the design of the rotating elements the principal difference between the two common types of purifiers?
18. In what type of purifier does the oil enter and leave through the top of the bowl?
19. What is the purpose of the three-wing device in the bowl of a tubular type purifier?
20. When should a purifier be operated at less than rated capacity?
21. When a purifier is used as a separator, what will be the result if the bowl is not primed with water?

22. What is the principal factor determining the length of time required to purify a lubricating oil?
23. Should the pressure or the temperature of the oil admitted to a purifier be increased in order to facilitate purification?
24. What is the result if the pressure on the oil admitted to a purifier is reduced? Why?
25. What determines the size of the discharge ring to be used for the purification of a given oil?
26. How can the general efficiency of a purifier be determined, if an analysis of the purified oil cannot be made?
27. What type of chemical compound is included in a grease which is to be used where operating temperatures and loads are not excessive but where moisture is present?
28. Why is graphite grease not recommended as a lubricant for ball bearings or roller bearings?

CHAPTER 10

ENGINE LUBRICATING OIL SYSTEMS

Minimizing friction between the bearing surfaces of moving parts and dissipating heat have already been emphasized as the primary functions of lubrication. The engine system which supplies the oil required to perform these functions is of the pressure type in practically all modern internal combustion engines. Even though many variations exist in the details of engine lubricating systems, the parts of such a system and its operation are basically the same, whether the system is in a Diesel or a gasoline engine. Since the Diesel engines in use in the Navy greatly outnumber gasoline engines, the information in this chapter deals primarily with the lubricating systems of Diesel engines. If you understand the lubricating system of a Diesel engine, learning about the system of a gasoline engine will be relatively easy.

As an EN3, you are required to be able to trace the path of oil through an engine, and to know the reasons for system ventilation. In addition, you are required to know about several factors dealing with the operation and maintenance of an engine lubricating system. This chapter provides information which will aid you in meeting requirements dealing with oil flow and system ventilation. Information related to the operation and maintenance of lubricating systems is given in subsequent chapters.

PARTS OF A LUBRICATING OIL SYSTEM

The lubricating system of an engine may be thought of as consisting of two main divisions, that external to the engine and that within the engine. The internal division,

or engine part, of the system consists principally of passages and piping; the external part of the system includes several components which aid in supplying the oil in the proper quantity, at the proper temperature, and free of impurities. In order to meet these requirements, the lubricating systems of many engines include, external to the engine, such parts as tanks and sumps, pumps, coolers, strainers and filters, and purifiers.

Tanks and Sumps

The lubricating systems of propulsion installations include tanks which collect oil that has been used for lubrication and cooling, so that this oil can be recirculated through the engine. The oil system of some installations also includes a sump or drain tank under the engine. These tanks collect the oil as it drains from the engine crankcase. Storage and sump tanks are not common in auxiliary engines; in these engines the oil supply is generally contained directly within the engine oil pan or sump.

Pumps

Positive-displacement rotary-gear type pumps (see *Fireman,* NavPers 10520–A) are used to deliver oil under pressure to the various parts of the engine. These pumps are engine-driven. Lubricating-oil pumps supply oil at pressures that are closely adjusted to the engine requirements, since the pump is driven from the engine camshaft or, in some engines, directly from the crankshaft. Changes in engine speed cause corresponding changes in pump output.

If lubrication is required prior to engine starting, detached electric or hand priming pumps are used to supply the necessary oil. Detached pumps may also be used for filling the sump tanks from storage tanks, supplying oil to the purifier, and flushing the engine lubricating system.

The pressure maintained by most lubricating oil pumps is controlled by pressure-regulating valves or pressure-relief valves built directly into the pump. In some cases, valves separate from the pump are used for pressure con-

trol purposes. Most oil-pressure regulating devices recirculate excess oil back to the pump. Some pumps, however, are designed to discharge excess oil directly into the engine sump or the crankcase.

Coolers

The lubricating oil systems of most engines, especially large ones, must include coolers (heat exchangers) to maintain the oil temperature within the most efficient operating temperature range. The oil, as it passes through the operating engine, will absorb heat from the metal parts with which it comes in contact.

Since engine oil is recirculated and used over and over, the oil is continually absorbing additional heat. Unless provision is made to remove the heat, the oil temperature will rise to excessive values. At extremely high temperatures, oil tends to oxidize rapidly and form carbon deposits. Excessively high temperatures also cause an increase in the rate of oil consumption. Consequently, it is necessary to have oil coolers to remove excess heat from the oil if the lubricating qualities of the oil are to be retained.

The coolers used to remove heat from lubricating oil are of the same types as those used to remove heat from other fluids common to internal combustion engines. Since the liquid to which heat is transferred and the cooler are both commonly associated with the engine cooling system, additional information on heat transfer and coolers is given in the next chapter, which deals with engine cooling systems.

Filtering Devices

Strainers and filters are incorporated in the lubricating-oil system of an engine to remove abrasives and foreign materials, which tend to increase wear of engine parts and cause deterioration of the lubricating oil. Strainers are designed to remove large particles of foreign matter from the oil. Filters function to remove smaller particles, which pass through the strainer. Various types of strainers and filters are used in Navy installa-

tions. In Navy terminology, all metal-edge and wire-mesh devices are classed as strainers; devices which have replaceable, absorbent cartridges are called filters. The location and number of strainers and filters will vary, depending upon the type of installation.

STRAINERS.—Lubricating-oil strainers are made in both simplex and duplex types. A duplex strainer is essentially two strainer elements incorporated in one assembly. A manual valve is provided for directing the flow of oil through either of the elements. When duplex strainers are included in a lubricating system, one element can be bypassed and the element can be removed and cleaned without disturbing the flow of oil to the engine.

Every approved lubricating-oil strainer contains a built-in, spring-loaded or differential area, pressure-relief valve. The valve must be sufficiently large to bypass all of the oil around a clogged strainer, so that an uninterrupted flow of oil may be maintained to the engine.

Metal-edge type strainers consist principally of a strainer element surrounded by a case which serves as a sump to collect foreign material and water. The element consists of an edge-wound metal ribbon or a series (stack) of edge-type disks. Most strainers have devices for manually rotating the strainer element against metallic scrapers which remove material caught by the element. Strainers are usually provided with vents for releasing air from the system.

A strainer of the EDGE-WOUND METAL RIBBON TYPE is shown in figure 10–1. The strainer illustrated is so constructed that the oil required by the engine is continuously filtered, except when the element must be removed for cleaning or servicing. When an element is to be removed, the control valve handle is turned to the BYPASS position. When the control valve handle is in the BYPASS position, the oil flow is shunted through the strainer head; the element may then be removed without interruption to the oil flow to the engine. Under normal operating conditions, the oil comes into the strainer at the top and

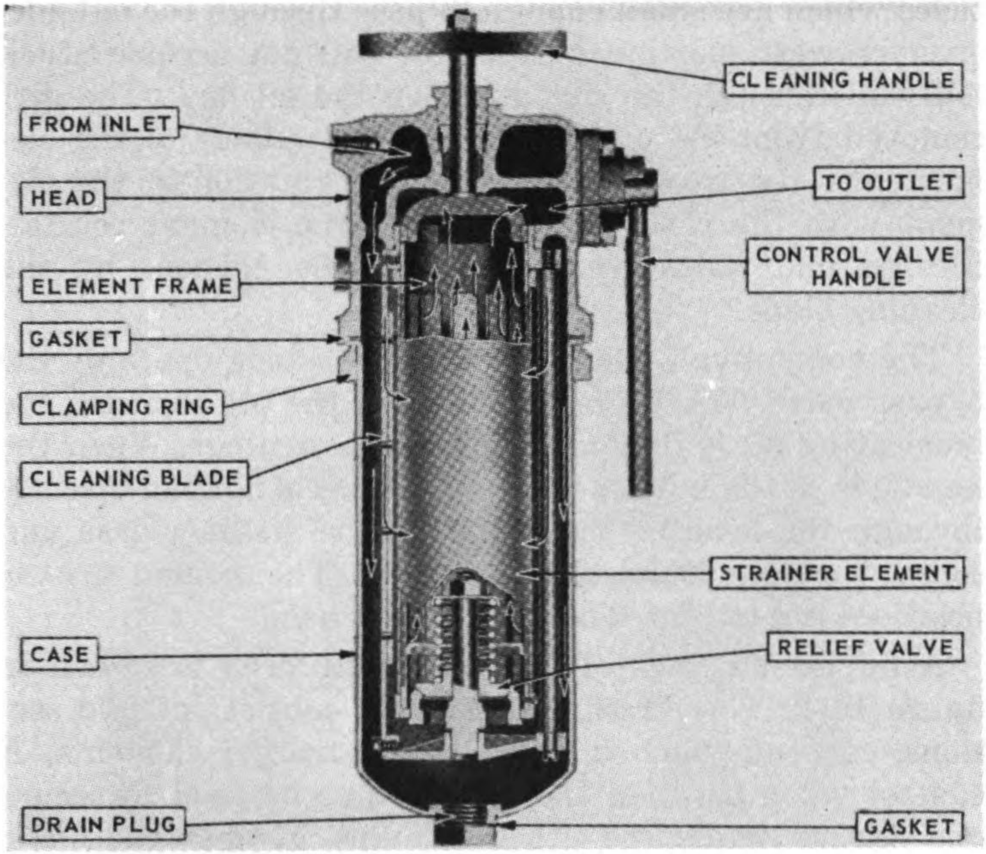


Figure 10–1.—Edge-wound metal ribbon type lubricating-oil strainer (GM 278A).

descends to surround the ribbon element. The oil then passes through the coils, into the center of the element, and then upward to the outlet passage.

The element consists of a closely compressed coil of stainless steel wire. The wire has been passed between rollers so that it is a wedge-shaped wire or ribbon, which has one edge thicker than the other. On one side of the wire, projections are spaced at definite intervals; the other side is smooth. The projections on one side of the wire touch the smooth side of the wire on the adjacent coil to provide appropriate spacing between adjacent coils. The thick edge of the wire is on the outside of the coil; a tapered slot is therefore formed from the outside to the inside of the coil, with the narrowest part of the slot on the outside. This arrangement ensures that the dirt par-

ticles which are small enough to pass through the outside, or narrowest, portion of the slot will not become stuck halfway through the slot and clog the oil flow. The dirt removed from the oil remains on the outside of the element and can readily be removed by rotation of the element with the cleaning handle. As the element rotates, foreign material is removed from the element by the cleaning blade.

The control-valve handle on the strainer operates the bypass valve. When the handle is in the ON position, the lubricating oil is flowing through the strainer. When the handle is in the BYPASS position, the oil is flowing directly through the head of the unit, and the strainer case and element can be removed and cleaned. The ON and BYPASS positions are indicated on the strainer head.

A duplex strainer of the EDGE-DISK TYPE is shown in figure 10–2. The strainer illustrated consists of two sections, each of which includes three strainer elements. A control valve between the two sections is used to secure one section while the other remains in operation. The secured section acts as a standby unit; it may be opened for cleaning and inspection without interruption to the straining operation.

A strainer element of the edge-disk type consists of an assembly of thin disks separated slightly by spacer disks. The assembly of one type of strainer element is illustrated in figure 10–3.

The lower end of a disk assembly is closed; the upper end is open to the strainer discharge. Oil entering the strainer assembly is forced down between the casing and disk assembly and then through the disks into the center of the assembly. The oil then passes up through the assembly and out the discharge outlet. In passing through the strainer, the oil must pass through the slots between the strainer disks. At the bottom of the strainer element a relief valve is provided to relieve pressure which would build up in the strainer if the slots became filled with foreign matter. The relief valve bypasses the oil up

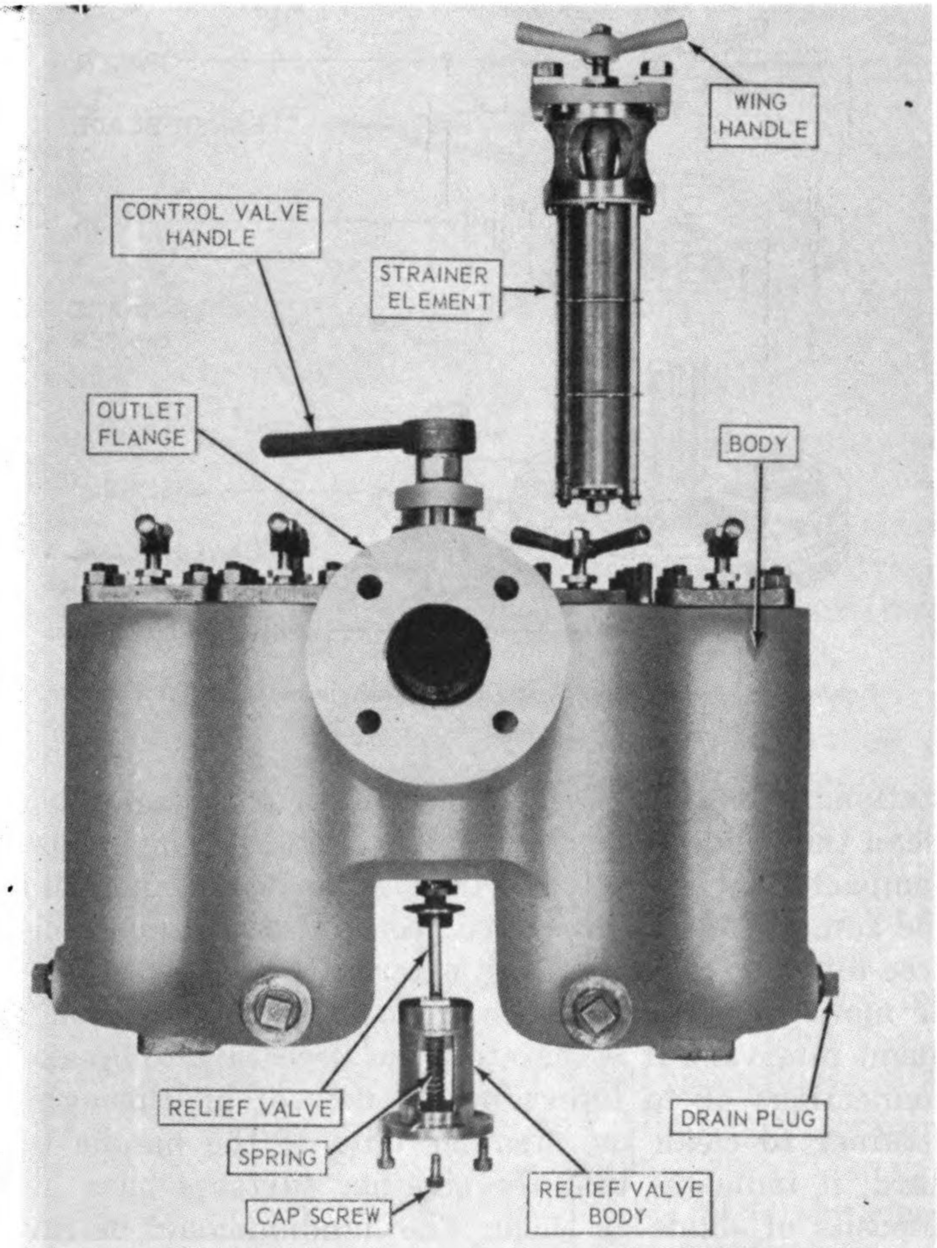


Figure 10–2.—Edge-disk type oil strainer (Cooper-Bessemer, GSB-8).

through the center of the strainer element and out the strainer discharge when a predetermined pressure is reached.

When the assembly is turned by means of the external, or wing, handle, the solids that have lodged against or between the disks are carried around until they meet the

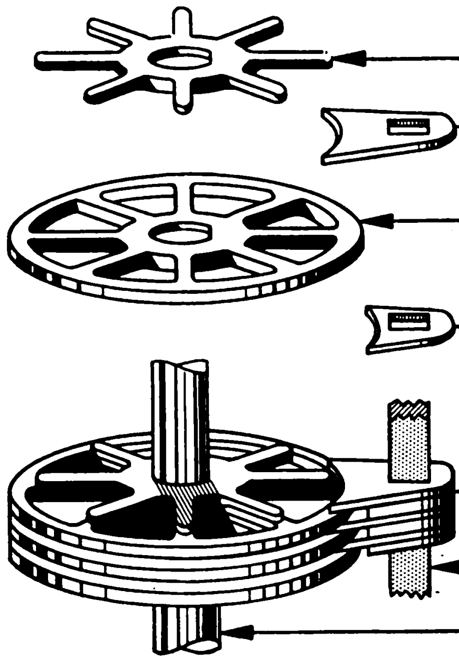


Figure 10—3.—Edge-disk type strainer element assembly (GM 268A).

stationary cleaner blades. The stationary cleaner blades clean the solids from the strainer surface. The solids are compacted by the action of the cleaner blades and fall into the sump of the strainer. To keep the strainer in a clean, free-filtering condition, the external handle is given one or more complete turns in a clockwise direction at frequent intervals. It is therefore not necessary to break any connections or to interrupt the flow of oil through the strainer to clean the strainer unit. If the handle turns hard, it indicates that the strainer surfaces have heavy deposits of solids on them. The handle should be turned frequently; there is no danger of turning the handle too often, as there are no parts to wear out. If the strainer cannot be cleaned by turning, the head and disk assembly must be removed and soaked in a solvent until the solids have been removed.

Strainers installed on the suction or intake side of the pressure pumps are generally of the WIRE-MESH (SCREEN) TYPE. Units of this type are generally referred to as coarse strainers. In many cases, screen-type strainers are

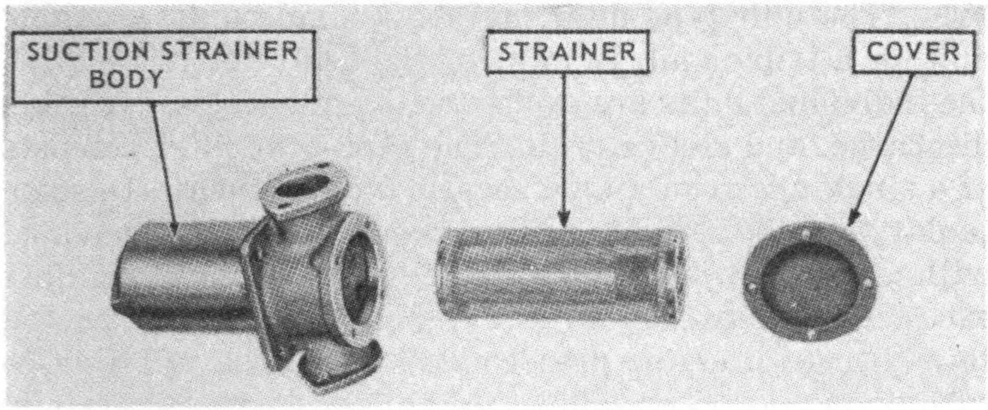


Figure 10–4.—Screen-type lubricating-oil strainer (GM 278A).

located in the oil pan or sump. One type of screen strainer is shown in figure 10–4. Another type of screen strainer and its location are shown in figure 10–14 of this chapter and in figure 9–13, *Fireman,* NavPers 10520–A.

FILTERS.—In filters approved by the Navy, the absorbent material is composed of such substances as cellulose, cotton yarn, cotton waste, and paper disks. Materials such as mineral wool, Fuller's earth, and activated charcoal remove the compounds from additive-type oils. Such materials are not permitted in filters used on engines in naval service.

Lubricating-oil filters are of the simplex type only. Filters may be located directly in the pressure lubricating oil system or they may be installed as bypass filters. When installed in the pressure system, a filter must contain a built-in, spring-loaded, pressure-relief valve. The valve must be sufficiently large to bypass all oil to the engine in the event the filter element becomes restricted.

Bypass filters require an orifice plate in the line to the filter. This plate controls the amount of oil which is removed from the lubricating-oil pressure system. The amount of oil which flows through a bypass filter is only a small percentage of that flowing through the pressure system. The oil from a bypass filter is returned to the sump tank.

Filters vary as much in design and construction as strainers do. Filters may be of the UNIT TYPE or the TANK

TYPE. The unit type filter may be a single unit, a double unit, or a triple unit. In units of the double or triple type, the individual units are connected, by manifolds, for inlet, discharge, and sludge drain. The tank-type filter consists of a single tank containing several filter elements. In some tank-type filters, each filter-element holder is provided with a relief valve which protects the element against excessive pressure. Other tank-type filters are constructed to withstand pressure greater than that of the relief-valve setting on any of the pumps in the lubricating-oil system. Examples of a single-unit type filter and a tank-type filter are shown in figures 10–5 and 10–6, respectively.

Only the main parts of an engine lubricating system have been discussed to this point. As a Fireman, you

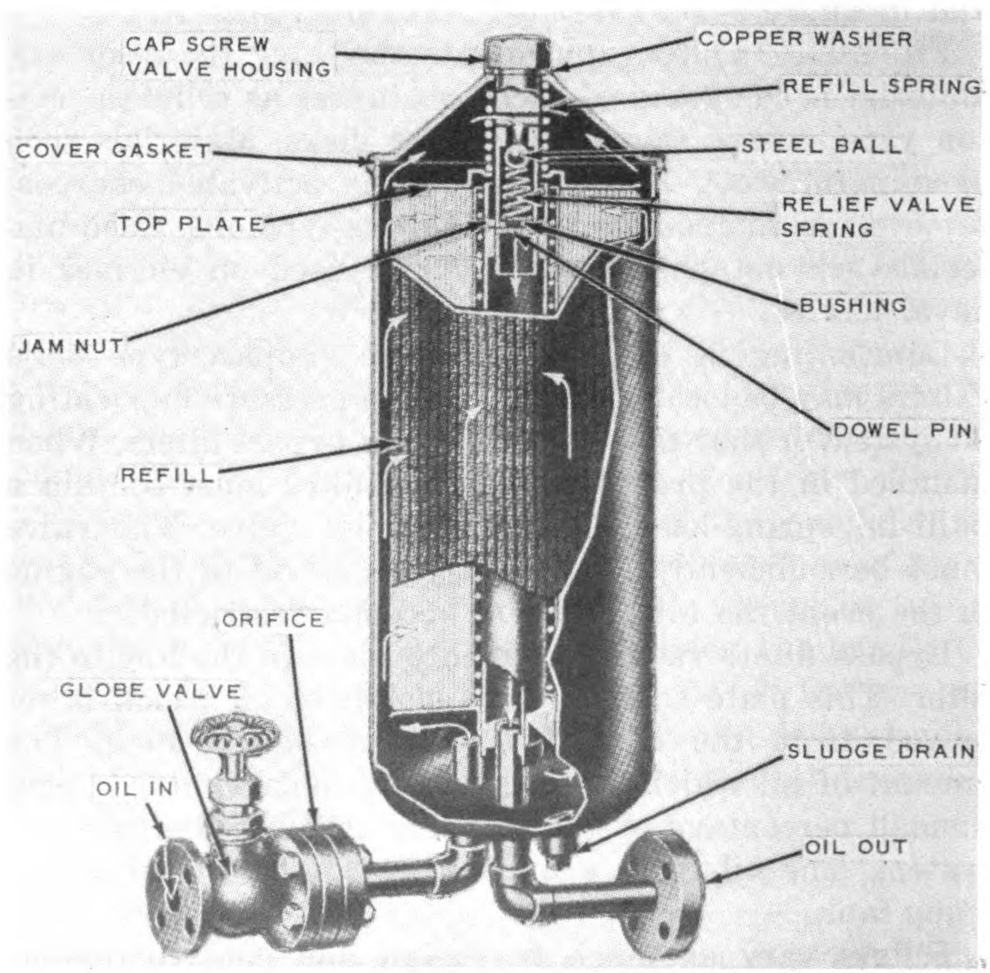


Figure 10–5.—A single-unit type lubricating-oil filter (GM 268A).

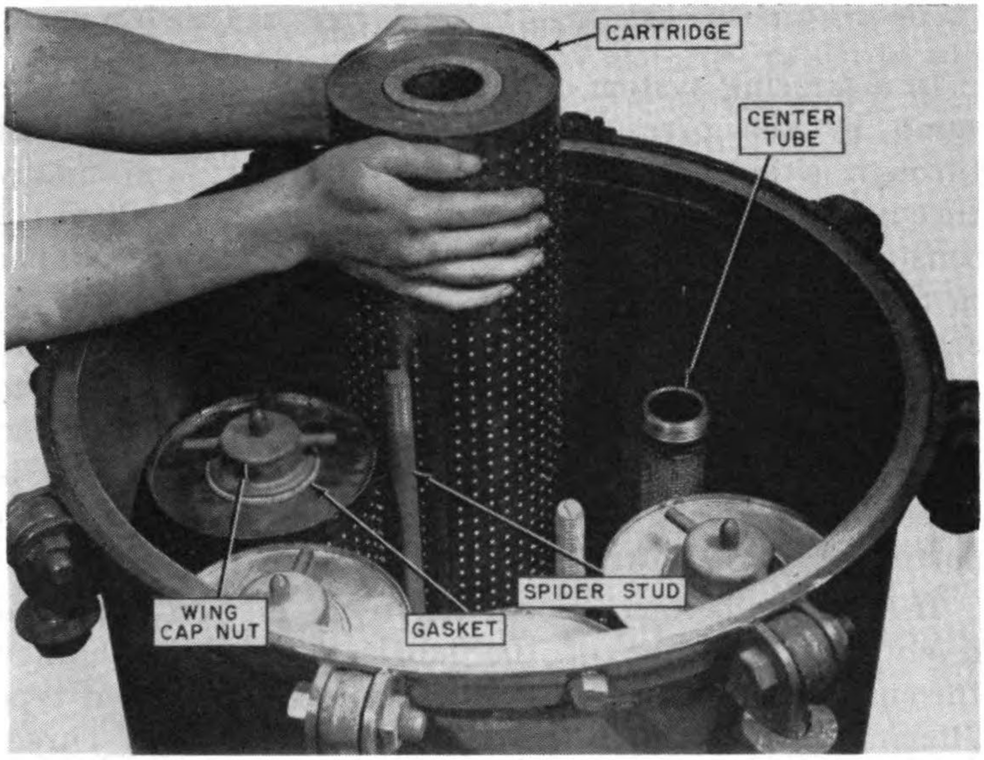


Figure 10–6.—Tank-type lubricating-oil filter (Cooper-Bessemer GSB-8).

should be familiar with the piping and the gages, thermometers, and other instruments essential to complete the system. The remainder of this chapter deals with the types of lubricating oil filtering systems, the path of oil through a lubricating-oil system (including the internal or engine part of the system), and how and why lubricating-oil systems are ventilated.

LUBRICATING OIL FILTERING SYSTEMS

The strainers and filters of Navy Diesel engine installations are incorporated in what is generally referred to as the lubricating oil filtering system. An engine used by the Navy may utilize one of four types of filtering systems: shunt, full flow, sump, and bypass. The type of filtering system used depends upon the type of installation and its application. In general, systems of the shunt and sump types are used with large installations; bypass systems are used in small installations, such as those in powerboats.

Shunt Filtering System

In a filtering system of this type, oil is taken from the sump by the pressure pump and is discharged first through a strainer, then through a filter, and finally through a cooler, to the engine. The pump delivers a constant amount of oil per revolution, but the resistance in the strainer and the filter varies, depending upon the condition of these units and the temperature of the oil. In order that an adequate flow of oil will be delivered to the engine at any particular engine speed, the filter and the strainer are each provided with a bypass, which is fitted with a spring-loaded bypass valve through which a portion of the oil flows.

If the filter becomes clogged or if the oil is cold, a relatively large portion of the lubricating oil is shunted through the bypass. Strainers and filters in a shunt-type filtering system may also be manually bypassed. Three-

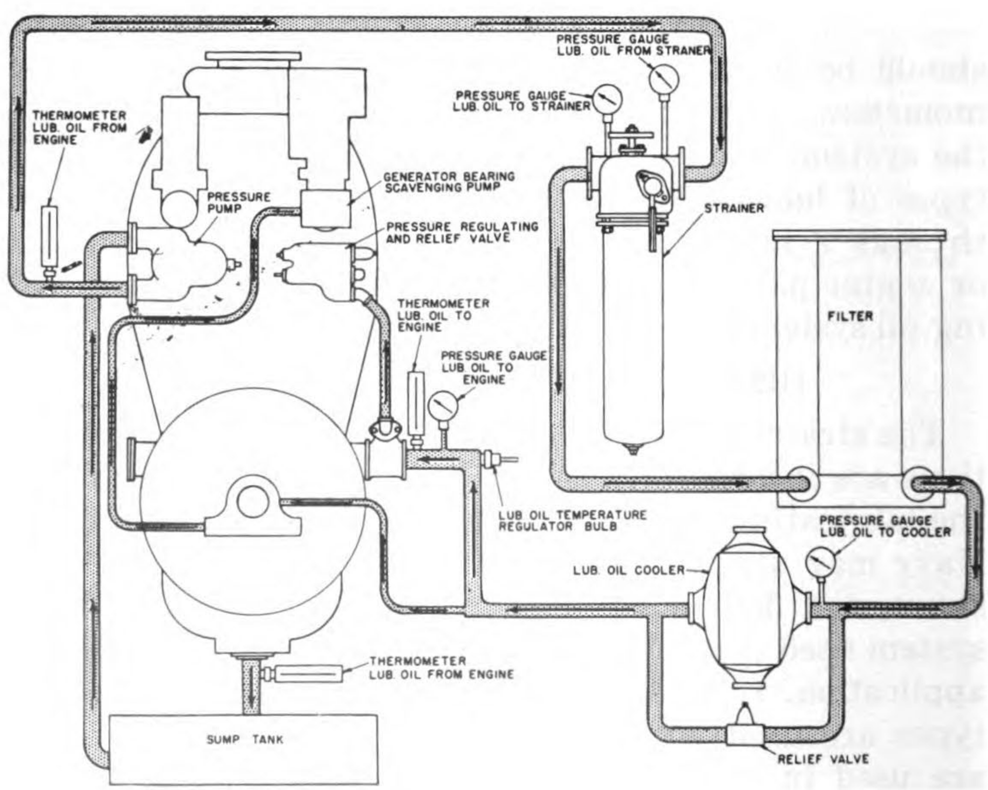


Figure 10–7.—Shunt-type lubricating-oil filtering system (GM 278A).

way valves are provided for bypassing each unit, so that strainers may be cleaned or filter elements replaced while the engine is operating. A schematic diagram of a shunt-type filtering system is shown in figure 10–7.

Full-Flow Filtering System

This system is similar to the shunt system with the exception that filter elements are designed for high flow rates permitting the entire pump delivery to pass through the elements. The bypass valve serves the same function as in the shunt system, however, the valve will remain closed during normal engine operation. The schematic arrangement is identical to that shown in figure 10–7. Some later installations are provided with an external bypass line with a relief (unloading) valve in this line in lieu of being built-in the filter. A differential pressure gage installed across the valve will indicate when filter elements are clogged and require changing.

Sump Filtering System

This type of system is similar to the shunt system, except that the filter is placed in a separate recirculating system which includes a separate motor-driven pump. This type of system permits the lubricating oil to circulate through the filter even when the engine is secured. In the sump-type filtering system, the oil to be filtered is taken from the sump by the motor-driven pump, forced through the filter, and then discharged back to the sump. Oil to the engine is taken from the sump by the engine-driven pump and forced through the cooler and strainer to the engine. The path of the oil through a sump-type filtering system may be seen in figure 10–8.

Bypass Filtering System

In many respects, a bypass system is similar to a shunt system. The primary exception is that a portion of the oil discharged by the pressure pump in the bypass system is continuously bypassed back to the sump, through the filter or filters. In order that sufficient oil will be supplied to the engine, the amount of oil permitted to flow through the filter is limited by the size of the piping and if neces-

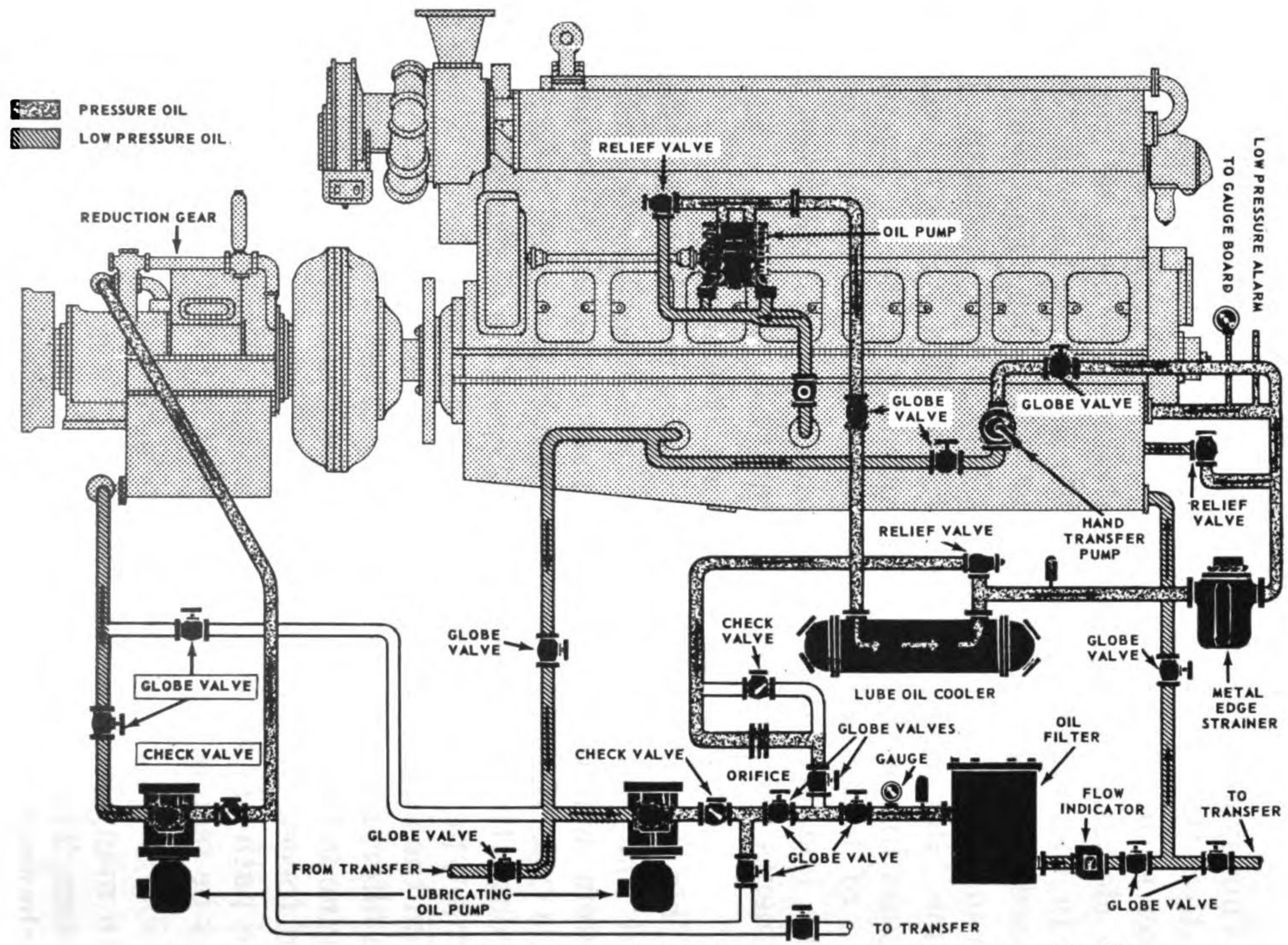


Figure 10—8.—Sump-type lubricating oil filtering system (Cooper-Bessemer, GSB-8).

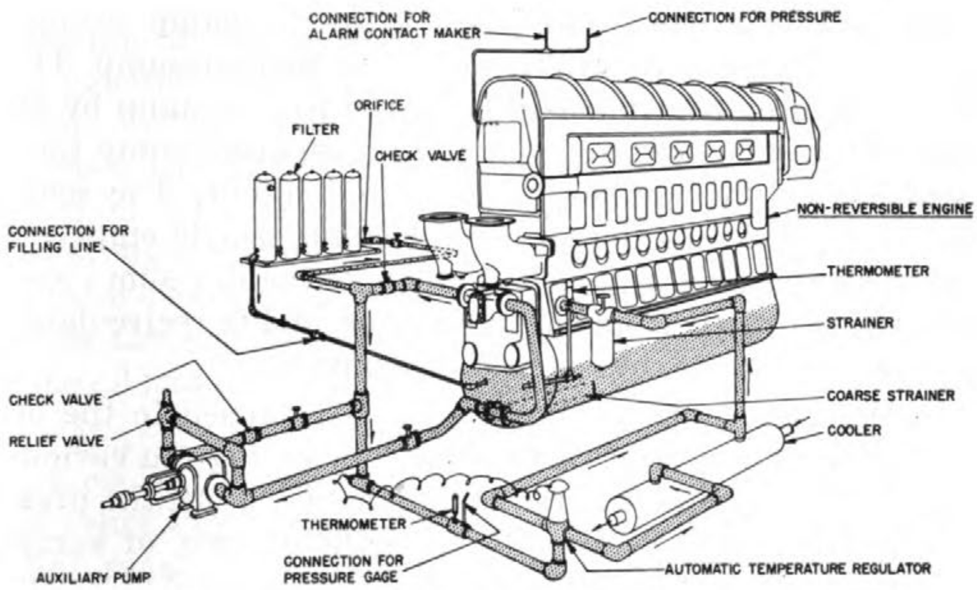


Figure 10–9.—Bypass-type lubricating oil filter system (FM 38D8 1/8).

sary, by an orifice. A valve is provided so that the flow of oil to the filter may be stopped. The arrangement of a bypass filtering system for one type of engine is shown in figure 10–9.

PATH OF OIL THROUGH THE ENGINE LUBRICATING OIL SYSTEM

Diesel Engines

The path of the oil through the system piping and through the components external to the engine for three types of Diesel installations has been illustrated in figures 10–7, 10–8, and 10–9. It is apparent from these figures that the sequence of the components through which the oil flows is not always the same. In general, arrangement of the oil-system parts external to the engine will depend on the type of engine and the installation, and the path of oil through the external components will be governed by the type of filtration system used.

That part of a lubricating-oil system which is external to an engine may be classified according to the type of filtering system used; the engine, or internal, part of a lubricating-oil system may be classified as either a dry-

sump type or a wet-sump type. In the dry-sump system, the oil is returned by gravity to an oil pan, or sump. The oil is delivered continuously from tne pan or sump by an engine-driven scavenging pump, to a separate sump tank (which may include the strainer and filter). The scavenging pump keeps the oil pan, or sump, nearly empty of oil; therefore this system is known as the dry-sump system. Oil is drawn from the sump tank and is recirculated through the engine, by the pressure pump.

In the wet-sump system, the oil is returned to the oil pan or sump by gravity flow after lubricating the various parts of the engine. In systems of the wet type, the pressure pump draws oil directly from the oil pan, or sump, and recirculates the oil through the filtering equipment and the engine. The systems illustrated in figures 10–7, 10–8, and 10–9 are of the wet-sump type. Note that these systems do not include a scavenging pump in the lubricating-oil system.

Even though differences exist in the design and arrangement of various Diesel-engine lubricating systems, the systems of most engines are similar in many respects. Some of the similarities and differences in lubricating-oil systems are pointed out in the following descriptions. Learning to trace the path of oil through the lubricating-oil system of an engine will be easier if reference is made to the illustrations shown in connection with each of the descriptions which follow.

GM 278A.—The shunt-type, wet-sump system illustrated in figure 10–7 is used on some models of General Motors 278A engines. The pressure pump, driven by the camshaft gear train (fig. 10–11), draws oil from the sump tank and forces the oil through a safety relief-valve at the discharge side of the pump. In this case, the pump forces the oil through a strainer, a filter, and a cooler to the engine oil inlet. After circulating through the engine, the oil drains into the oil pan and then into the sump tank, from which the oil is recirculated.

Note the generator-bearing scavenging pump and the

oil line in figure 10–7. When the engine is used to drive a generator, oil for the generator bearings is taken from the lubricating-oil piping, between the cooler and the engine inlet. When the engine is running, the bearing drains are placed under a suction head by the generator bearing scavenging pump to prevent flooding of the main generator-bearings. The oil is drawn from the bearing drains into the engine lubricating system and then drains into the oil pan and back to the sump tank.

Mercury thermometers are located at the lubricating-oil cooler inlet and at the engine inlet. A bypass line with a relief valve is provided to bypass the cooler when, for any reason, the cooler cannot handle the full-flow volume. This bypass is also used when cooling of the oil is not required, as when an engine is started in cold weather.

Duplex-type pressure gages are provided in the system, to register the oil pressure at the engine inlet and at the inlet and outlet of the lubricating-oil strainer. The system is provided with a low-pressure alarm consisting of a pressurestat, at the engine inlet, which energizes a horn and light whenever the oil intake pressure drops to, or below, a predetermined level. Continuous-reading thermometers indicate the temperature of the oil drawn from the engine.

The path of oil through the engine, or internal, part of the lubricating-oil system is illustrated in figures 10–10 and 10–11.

The lubricating oil enters the engine at a connection on the control side of the camshaft-drive housing (fig. 10–11). The relief valve ahead of the inlet keeps the oil at the proper pressure. Any oil bypassed by the relief valve returns to the camshaft-drive housing, from which it drains to the oil pan.

From the engine inlet connection, the oil flows to the main lubricating-oil manifold (galley), which extends the length of the engine (fig. 10–10) and is bolted to the bottom of the main-bearing supports. The oil flows from the

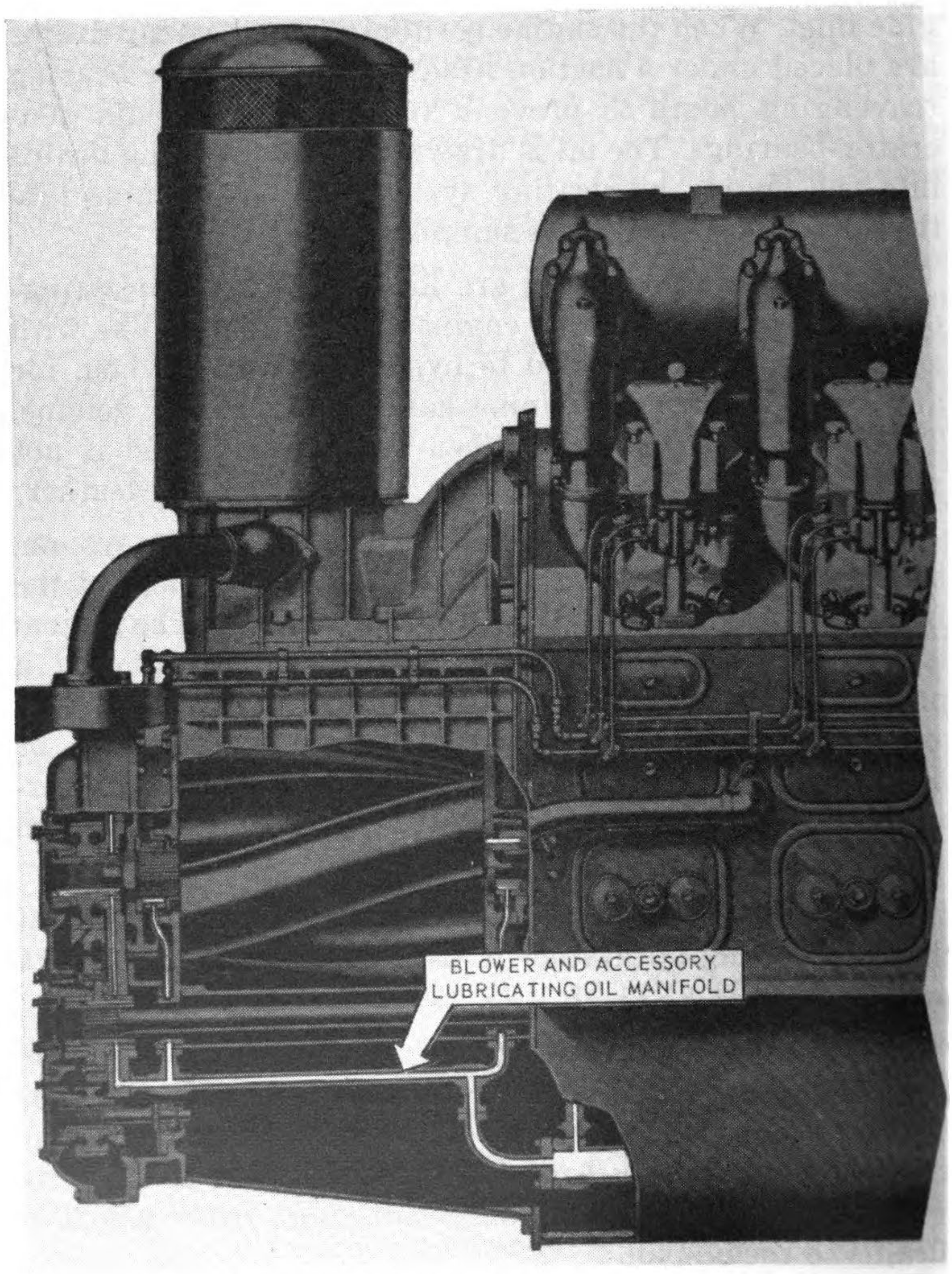


Figure 10–10.—Engine lubricating-oil system (GM 278A).

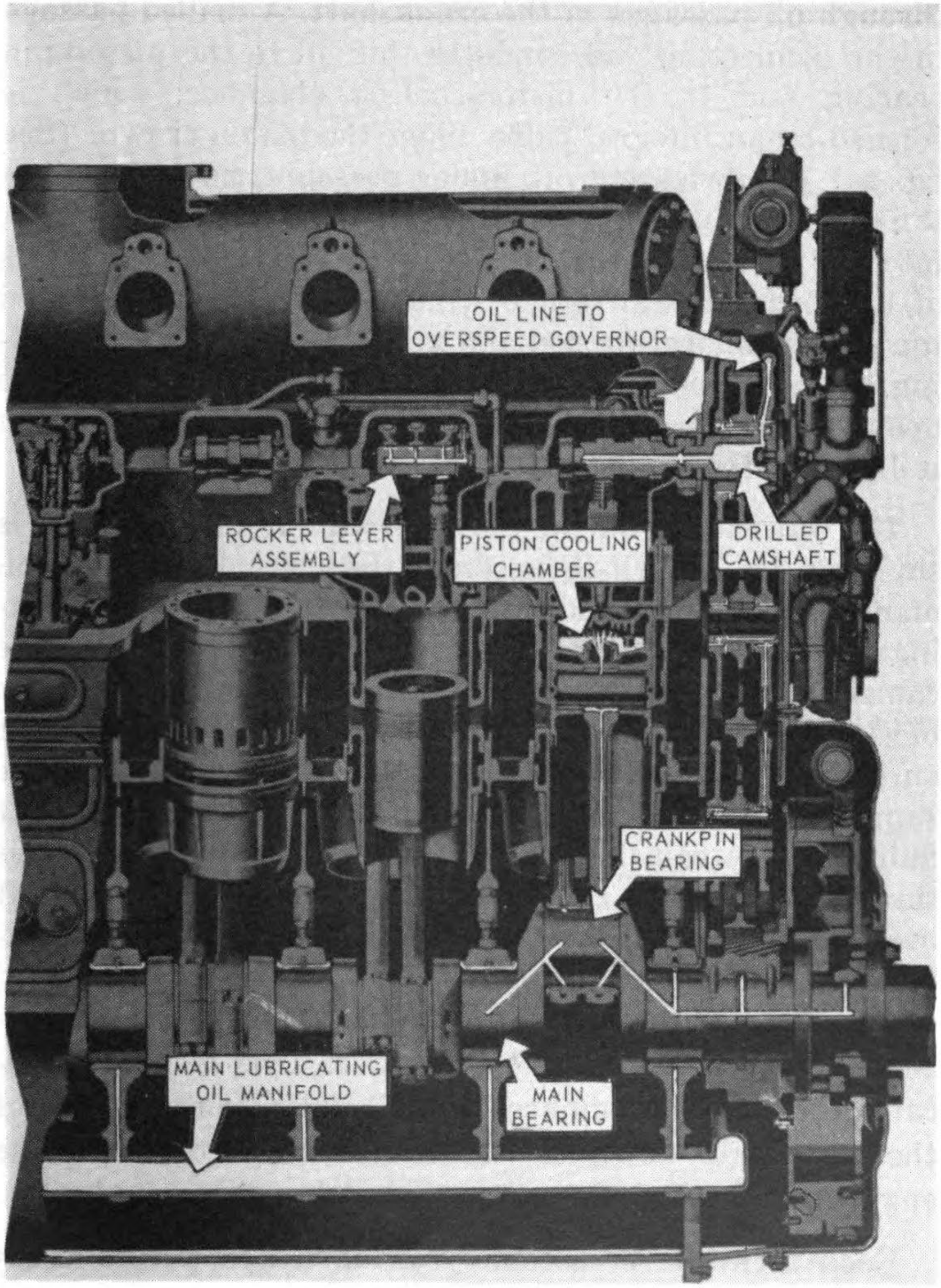


Figure 10–10.—Continued.

manifold, up through drilled passages in the supports, to each main bearing. The crankpin bearings are lubricated with oil that is received from the adjacent main bearings through oil passages in the crankshaft. A drilled passage in the connecting rod conducts this oil to the piston-pin bearing and to the piston-cooling chamber, which is formed by an integral baffle under the piston crown. (See fig. 4–1.) Lubricating oil, under pressure, flows from the top of the connecting rod, through an oil-sealing assembly, into the cooling chamber. The sealing assembly consists of a bronze oil-seal saddle which rides on the machined top of the connecting rod and is held against the connecting rod by a spring. The heated oil overflows, through two openings in the integral baffle, to the oil pan, from which it drains to the sump tank.

The lubricating oil for the camshaft-drive gear train is supplied, by branch lines, from the main lubricating-oil manifold. These branch lines conduct oil to the lubricating-oil distributor block (fig. 10–11) on each side of the camshaft-drive housing. From each of the distributor blocks, a pipe supplies oil to the bearing of the drive gear on each camshaft. The drilled camshafts (fig. 10–10) are supplied with oil through passages in the camshaft-gear hubs and the camshaft-drive sleeves. The oil then passes through the hollow camshafts and supplies the camshaft bearings by passing through radial holes in the camshaft-bearing journals. Oil for lubricating the rocker levers and cam rollers flows through a tube from the camshaft-bearing cap at each engine cylinder. This oil also lubricates the valve assemblies. The oil flows from the end of the camshafts down the camshaft drain tubes to the engine oil pan.

Each rocker-lever assembly is lubricated with oil that is received from an adjacent camshaft bearing (fig. 10–10). The oil flows from the top of the camshaft bearing, through a tube, to the plate connection that is fastened to one end of the rocker-lever shaft. From this connection,

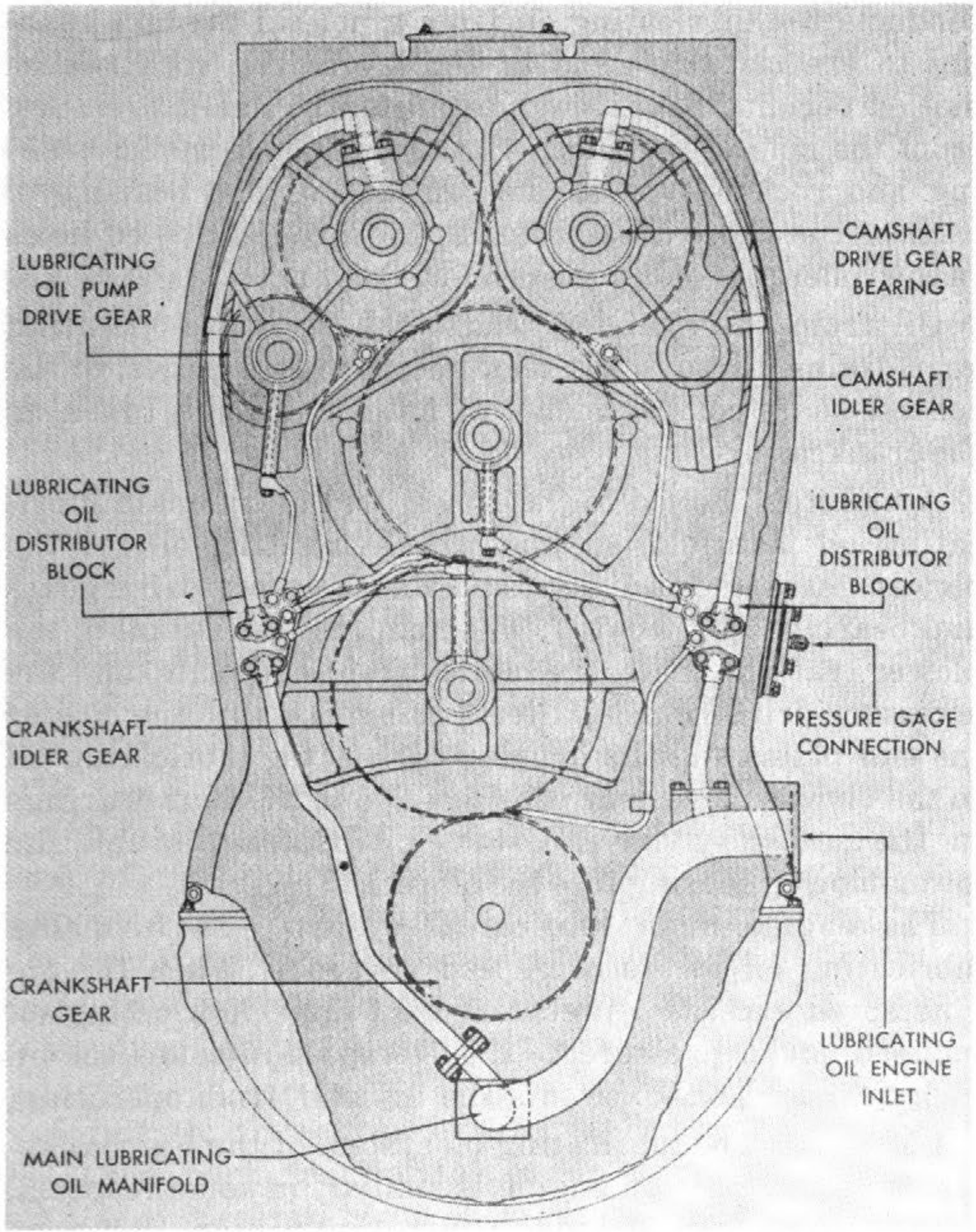


Figure 10–11.—Camshaft drive lubricating-oil lines (GM 278A).

the oil flows through drilled passages in the rocker-lever shaft to the three bearings in the rocker-lever hubs.

A drilled passage in each of the rocker-lever forgings conducts the lubricating oil from a hole in the hub bushing to the camshaft end of the lever. The rocker-lever motion permits oil to flow intermittently, under pressure, from the hole in the shaft, through one hole in the bushing and rocker-lever to the cam roller. The bearing in each of the cam rollers receives oil through drilled holes in the roller pin and in the bearing bushings.

Oil from the cylinder heads and the valve-operating gear drains, through the micrometer-link passages, to the control shaft compartment; and then, through tubes, to the crankcase.

A manifold, bolted to the blower end of the main lubricating oil manifold, supplies the lubricating oil for the blower gears and bearings, and the accessory-drive gears and bearings (fig. 10–10). The manifold carries oil to the blower rear-end plate, the blower front-end plate, and the accessory-drive housing. Steel tubing cast into the ribs of the end plates and the housing carries the lubricating oil to the blower-drive gear bearings and to the gear bearings in the accessory drive. Excess oil drains through the lower-blower housing into the oil pan.

The engine main lubricating system also furnishes lubricating oil to the overspeed governor. When the engine speed exceeds a predetermined limit, lubricating oil pumped, under pressure, to the overspeed injector-lock on each cylinder head prevents the injector from operating.

FM 38D.—The lubricating-oil system of the Fairbanks-Morse opposed-piston engine is similar, in some respects, to the system described in the preceding section. However, a bypass-type filtration system is used on the Fairbanks-Morse engine. Note (fig. 10–9) that, in the FM 38D engine, the oil is taken directly from the oil pan and not from a sump tank. (Some FM engine installations are equipped with sump tanks.) Other differences exist because of differences in the design of the FM 38D and the

GM 278A engines. Some of these differences can be noted by comparing the following description with that in the preceding section, and by making reference to the illustrations for both engines.

As is shown in figure 10–9, the attached positive-displacement gear pump draws lubricating oil, through a coarse strainer, from the oil pan. The strainer is mounted inside the oil pan. The pump, with a built-in relief valve, is mounted on a plate at the control end of the engine. The pump is driven by the lower crankshaft through gears and a flexible coupling. (Refer to fig. 6–9.)

From the pump, the oil (except that which is bypassed through the filters) is forced through the cooler(s) and through a fine strainer to the engine inlet. After circulating through the engine, the lubricating oil drains into the oil pan (or the oil pan and then the sump) for recirculation.

When the engine is used to drive a generator, a pipe connection ahead of the engine inlet supplies oil to the generator bearings. Oil from the generator bearings returns directly to the oil pan.

The temperature of the lubricating oil is regulated by an automatic temperature-regulator, which is located ahead of the cooler. The regulator bypasses some oil around the cooler. The amount of oil bypassed depends upon operating conditions and the viscosity of the oil. Thermometers are included in the system to indicate the temperatures of the oil between various components of the system. In some installations, a thermometer and a pressurestatic contact-maker are installed near the engine inlet. These parts function to close an alarm circuit whenever the oil pressure drops below a safe level.

An auxiliary, or standby pump is included in the system (fig. 10-9). This auxiliary pump is used if the attached pump fails. The pump may also be used to circulate the oil through the system when the engine is not operating.

The internal lubricating-oil system of the Fairbanks-

Morse opposed-piston engine consists principally of two oil headers and the passages necessary to provide oil for the lubrication and cooling of the bearing surfaces within the engine. The parts of the system and the path of the oil through the engine are shown in figure 10–12. Frequent reference should be made to this figure and to other figures mentioned in the following description as you study about the path of oil through an opposed-piston engine.

Lubricating oil from the strainer enters the oil inlet, which is located near the accessory drive (fig. 6–9). From the inlet, the oil flows through the lower header toward the blower end, where a vertical pipe provides passage to the upper header. (See longitudinal section view, fig. 10–12.)

Oil from the headers is forced, through pipes, to each main bearing; and then, through the crankshaft passages, to each crankpin bearing. From the crankpin bearings, the oil flows through the drilled connecting rod to the piston-pin bearings and the piston oil-cooling pockets. (See cross section of piston, fig. 10–12.)

The surfaces between the crankshaft flanges and the thrust bearing shells are lubricated by oil from the main bearing. Passages for the oil are provided by grooves in the thrust bearings.

The cooling oil from each lower piston is discharged, through the lower-piston cooling oil outlet, into the oil pan. Oil from each upper piston is discharged, through the upper-piston cooling outlet, into the compartment around the upper ends of the cylinders. This oil can drain either to the blower or to the control end of the engine and then down to the oil pan.

The two camshafts receive lubrication from the upper oil header. Oil enters the hollow camshafts through the camshaft bearings at the control end of the engine; small openings at each bearing journal allow oil to reach the camshaft-bearing surfaces. (See cross section of engine, fig. 10–12.) Oil from an opening in the end of each cam-

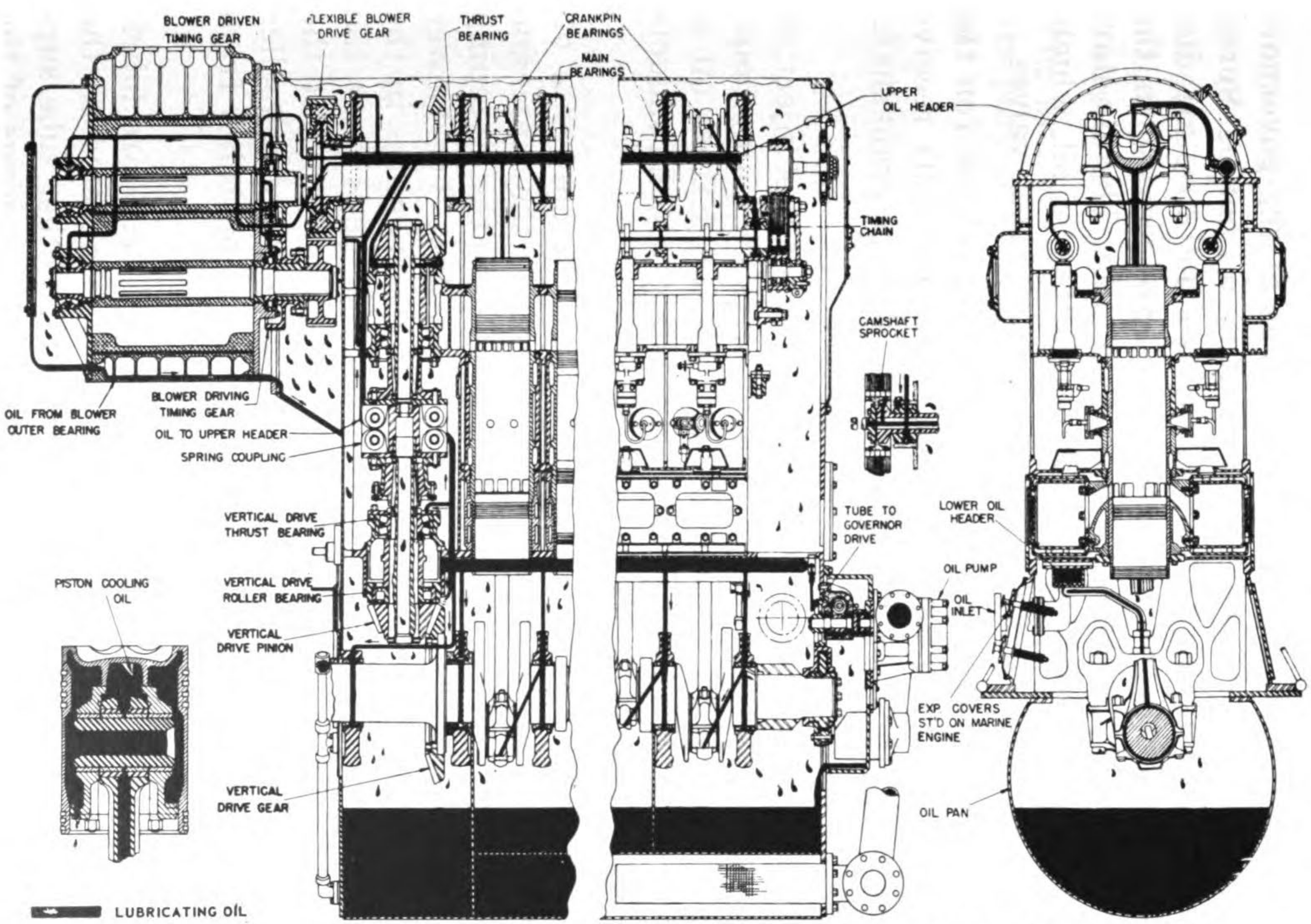


Figure 10—12.—Internal lubricating-oil system of an opposed-piston engine (FM 38D8 1/8).

shaft and excess oil from the No. 1 main bearing supply oil to the timing chain, at the control end of the engine. The oil spray from the timing chain provides lubrication for the bearings of the idler sprockets; for the control mechanisms, drive gears, and bearings of the governor; and for the water, fuel, and lubricating oil pumps. Spray from the timing chain also lubricates the air-start distributor and the air-start control valve, located in the lower part of the control end compartment. The air-start distributor valves admit a minute quantity of oil, which, carried by the air, lubricates the air-start check valves.

The drive bushings of the pump flexible-drive (on the control end of the lower crankshaft, 8, fig. 6–9) receive lubrication, through an opening in the lower crankshaft, from the control-end main bearing.

The tappet assemblies (2, fig. 6–9) of the fuel injection pumps are lubricated by oil which enters the pump housings from the upper engine compartment. Excess oil is drained through tubes to a return header, which conducts the oil to the control-end compartment.

The blower drive gears are lubricated by sprays of oil from special nozzles located on each side of the centerline of the engine. These nozzles are attached to the oil piping connecting the lower and upper oil headers. The blower flexible-drive gear is lubricated through openings in the drive spider. Oil is brought to these openings from the nearest main bearing by means of drilled passages in the upper crankshaft. The inner and outer blower-impeller bearings are lubricated by branches and oil tubes from the upper oil header.

The gears and pinions of the vertical drive are lubricated by a spray of oil from nozzles connected to the upper and lower oil headers by tubes. Another tube supplies oil to the roller bearings and thrust bearings of the lower pinion shaft.

After the functions of lubrication and cooling have been performed, the oil drains into the oil pan under the lower

crankshaft. From the pan, the oil is recirculated, by the pump, through the system.

GM 12–567.—The engine lubricating-oil system of the GM 12–567 differs in a number of ways from the two systems described and illustrated in the preceding sections of this chapter. Some of these differences will become apparent if the phantom diagram of the GM 12–567 lubricating-oil system (fig. 10–13) is compared with the systems already illustrated and described.

The pressure required to circulate the oil through the main part of the lubricating systems of the GM 16–278A and the FM 38D8 1/8 is created, in each case, by a single

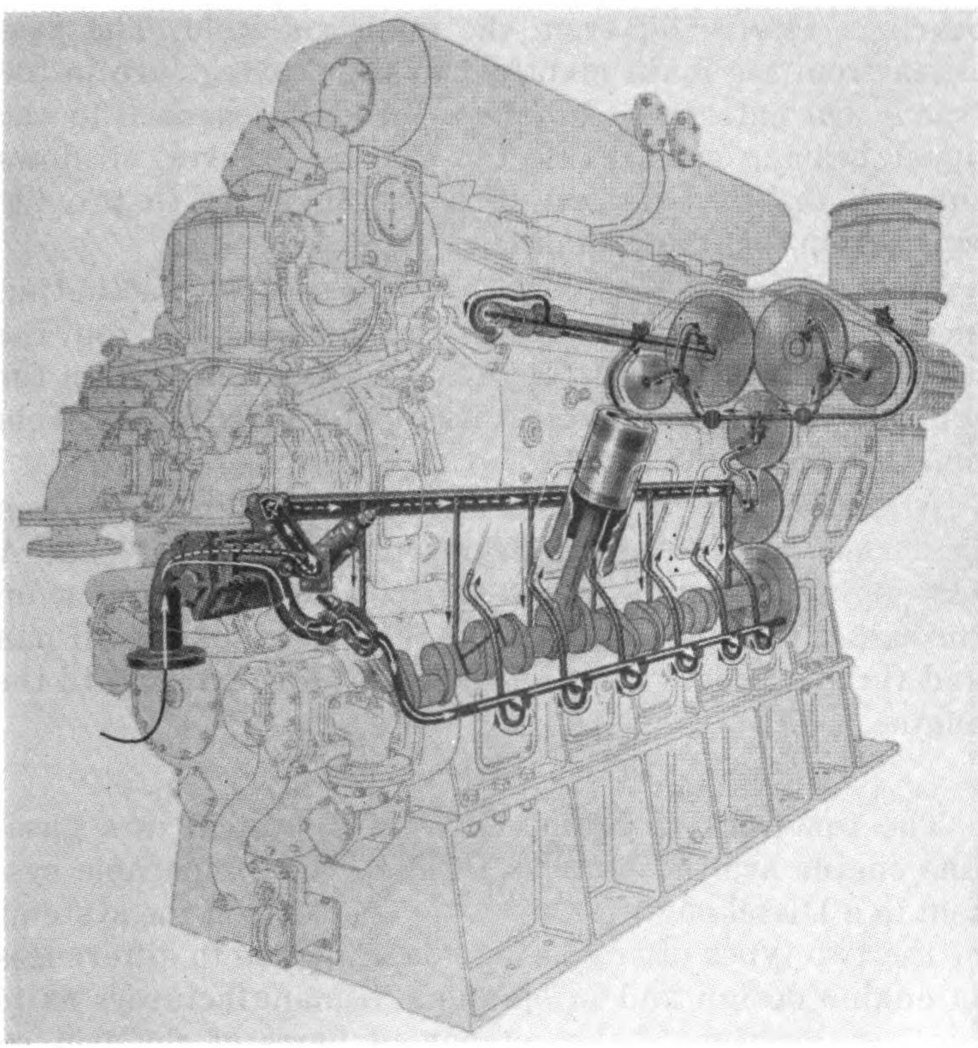


Figure 10–13.—Engine lubricating-oil system (GM 12–567).

pump. In the GM 12–567, two lubricating-oil pressure pumps are combined in a single unit; and two intake lines are connected to the oil supply from the strainer and cooler.

The connecting rods of the GM 12–567 do not contain oil passages as did the connecting rods of the engines already described. In order to get cooling oil to the piston, one of the pumps delivers oil through a manifold to the bottom of each piston, where a nozzle directs oil to the piston chamber. (See lower manifold, fig. 10–13.) The other pump forces oil through the main (upper) manifold, which is a V-shaped passage at the lower end of the space between the cylinder banks. Note that the main bearings receive oil from the main manifold. The passages from the main manifold to the bearings are in the frame. Oil enters the bearings through a groove in the upper bearing shell. From the bearing grooves, oil flows through drilled passages in the crankshaft to provide lubrication for the crankpin bearings.

The camshaft drive, the pump drive, the valve-actuating mechanism, and the blower drive all receive oil from the main manifold. Except for piston cooling, lubrication for the entire engine and accessories is provided by oil from main, or upper, manifold.

After the functions of lubrication and cooling have been performed by the oil, it drains back to the oil pan. A scavenging oil pump starts recirculation by drawing oil through a strainer and tube at the bottom of the oil pan and forcing the oil through the oil system external to the engine.

Gasoline Engines

The functions of the lubricating-oil system in a gasoline engine are the same as those of the comparable system in a Diesel engine. Any variance between the systems of the two types of engines is generally due to differences in engine design and in opinions of manufacturers as to the best location of the component parts of the system. In many cases, similar types of components are used in

the systems of Diesel and gasoline engines. The similarity of the parts used in the lubricating-oil systems of the two types of engines can be seen by comparing the lubricating-oil system for a small Diesel engine illustrated in *Fireman* 10520–A, figure 9–13, with the lubricating-oil system of a small gasoline engine, figure 10–14.

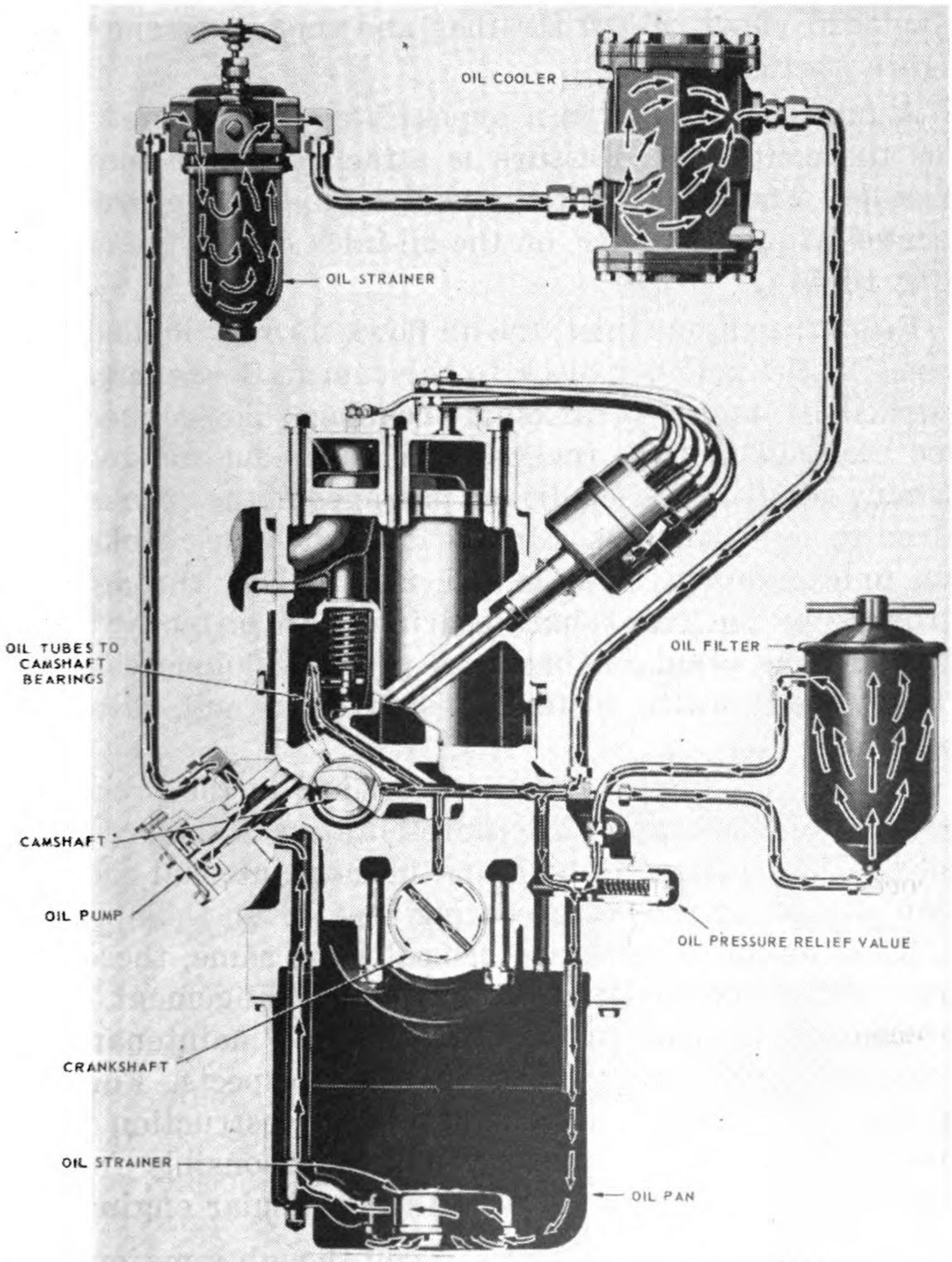


Figure 10–14.—The lubricating-oil system of a gasoline engine (Chrysler M-8).

CHRYSLER M–8.—The system illustrated in figure 10–14 is that of the Chrysler Royal Marine engine, Model M–8. Note the similarity of the path of oil flow to that in the Diesel engines already described. A pressure pump draws oil from the oil pan, through a screen-type strainer. From the pump, oil is forced through a strainer of the full-flow type and through a cooler before it enters the engine. Exploded views of the strainer and cooler are shown in figure 10–15.

A filter is included in a bypass line, and a relief valve for the control of pressure is attached to the main oil passage. The bypass filter and the relief valve are both located after the cooler, on the oil-inlet side of the engine (fig. 10–14).

From the engine inlet, the oil flows through drilled passages in the cylinder block to the camshaft bearings, the crankshaft, and the crankshaft bearings. The connecting-rod bearings and the reverse-gear and reduction-gear assembly receive oil from drilled passages in the crankshaft. Even though the oil passages revolve with the crankshaft, an uninterrupted flow of oil is supplied through oil grooves in the crankshaft bearings. An oil spray from holes in the crankpin bearings provides lubrication for the cylinder walls, pistons, piston pins, and valve assemblies.

The lubricating-oil systems described in the preceding sections of this chapter are representative of the pressure-lubrication systems to be found in most internal combustion engines of the reciprocating type. Even though most lubricating-oil systems are basically the same, these systems differ somewhat in design and arrangement. Also, procedures relating to the operation and maintenance of various engines may differ in some respects. For this reason, it is important that applicable instruction books be carefully studied when you are responsible for the operation and maintenance of any particular engine.

JOHNSON MOTORS ENGINE.—Even though a majority of the internal combustion engines have a definite lubricat-

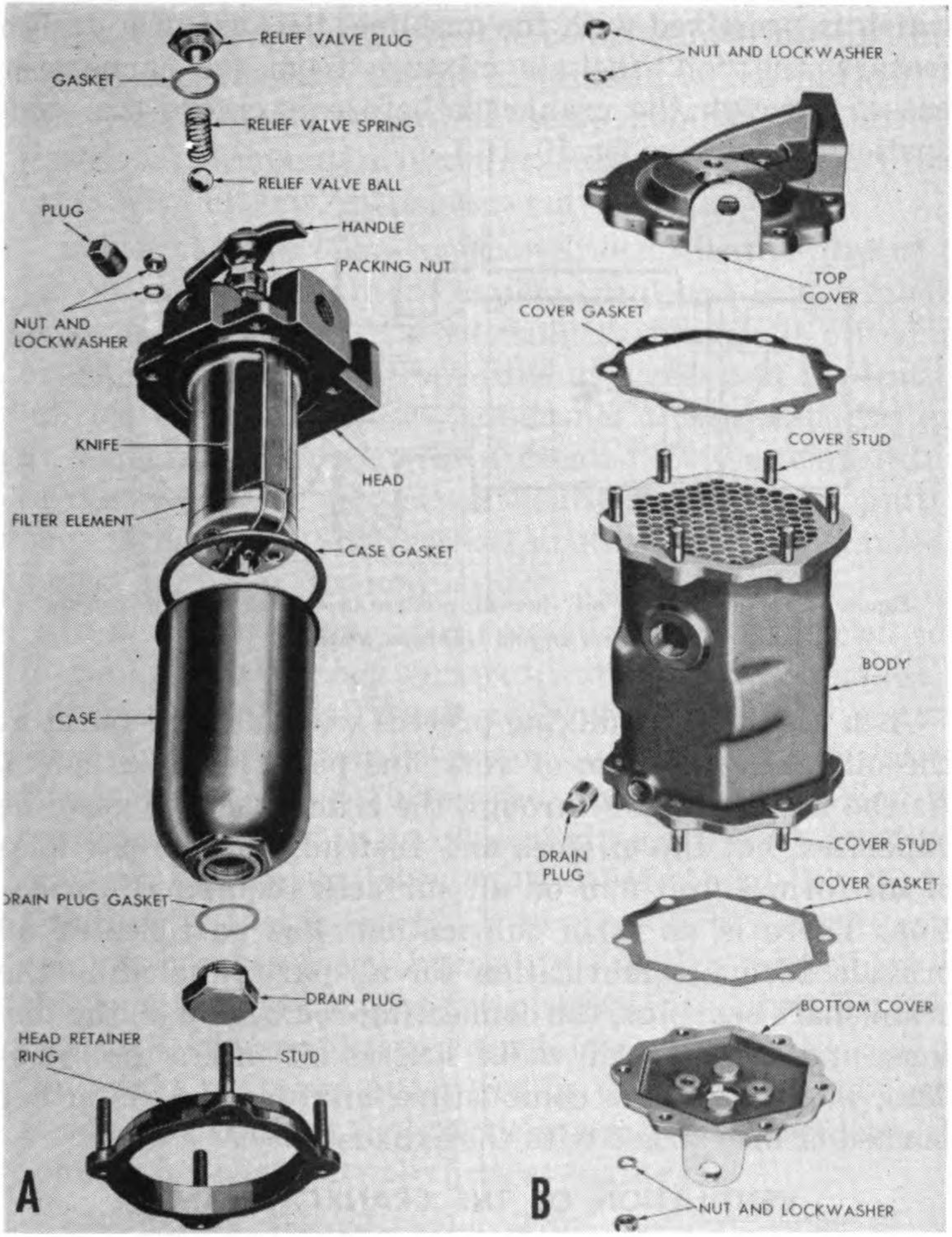


Figure 10—15.—Principal parts in the external lubricating-oil system of a gasoline engine (Chrysler M-8).

ing-oil system, there are some engines which have none. Such an exception to the general rule are some small gasoline engines. For example, the horizontal, opposed-cylinder, four-cylinder, two-stroke cycle gasoline engine used to power some P-500 pumps has no lubricating-oil system. In such engines, lubrication is provided by oil

which is premixed with the gasoline. Because of a design feature, the "oil"-fuel-air mixture from the carburetor passes through the crankcase before it enters the combustion space. (See fig. 10–16.)

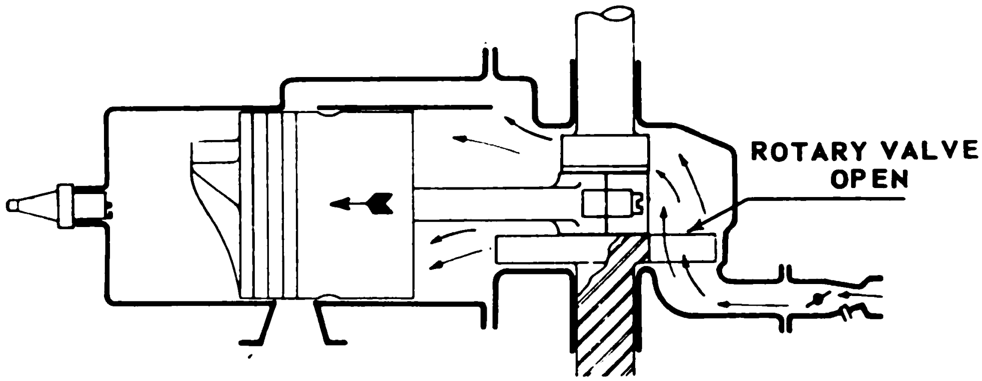


Figure 10–16.—Path of "oil"-fuel-air mixture in a small two-stroke cycle gasoline engine (Johnson Motors).

As a result of the mixing process within the carburetor, the oil takes the form of very fine particles or droplets. As the mixture flows through the crankcase, the gasoline vaporizes, but the oil does not. Instead, the fine particles of oil form an oil film on all surfaces requiring lubrication. There is no other lubrication. The particles of oil provide adequate lubrication for all parts, including the crankshaft bearings, the connecting-rod bearings, the pistons, and the cylinder walls. Excess oil enters the cylinders, along with the combustible mixture, and is either burned or discharged with the exhaust.

VENTILATION OF THE CRANKCASE AND OTHER ENGINE PARTS

Most engines are provided with some means of ventilating the internal cavities, or spaces, which are related to the lubricating-oil system. Systems may be vented directly to the atmosphere or through the engine intake-air system. The latter method is preferred in many marine installations, where the engine is located in an engineroom or other compartment. Venting the heated, fume-laden air directly to the atmosphere in a compartment

will seriously contaminate the compartment air and may create a fire hazard. On the other hand, if the lubricating-oil system is not vented in some manner, combustible gases may accumulate in the crankcase and oil pan. Under certain conditions, these gases may explode.

Under normal operating conditions, the mixture of oil vapor and air within an engine crankcase is not readily explosive. However, if a working part, such as a bearing or a piston, becomes overheated as a result of inadequate lubrication or clearances, additional oil will vaporize and an explosive mixture will be created. If the temperature of the overheated part is sufficiently high to cause ignition or if a damaged part strikes another part and causes a spark, an EXPLOSION may occur.

In addition to the vapor created by lubricating oil contacting extremely hot surfaces, vapor may accumulate in the crankcase as a result of blow-by past the pistons. Blow-by occurs when the piston is compressing the air or fuel-air charge and during the power event. During the compression event in gasoline engines, the blow-by of fuel may be sufficient to cause DILUTION of the lubricating oil. Dilution by fuel is less likely to occur in two-stroke cycle engines because the unburned fuel, which might blow-by the compression rings of the pistons, is trapped, before it can reach the crankcase, in the intake ports. As soon as the intake ports are uncovered by the piston on its downstroke, the trapped fuel particles are forced back into the combustion chambers by the scavenging air.

During the power event in all engines, some of the products of combustion enter the crankcase. The products of combustion contain a great deal of water vapor. The water vapor condenses when it contacts a relatively cool surface, often causing CORROSION and contaminating the oil by forming an EMULSION.

If the lubricating-oil system of an engine is properly ventilated, vapors which might be ignited by a local hot spot within the engine can be prevented from accumulating. Also, fuel dilution and water contamination will be

reduced considerably. If the crankcase of an engine is kept free of moisture and fuel, the oil will maintain an adequate viscosity for a longer period and corrosion will be kept at a minimum.

The method by which crankcase ventilation is accomplished varies, to a degree, from one engine to another. However, the functions of crankcase ventilation in all marine engine installations are to (1) prevent contamination of the engine-room atmosphere by heated or fume-laden air, (2) reduce or eliminate vapors and liquids which might cause dilution of the oil, corrosion of engine parts, or the formation of sludge, and (3) prevent the accumulation of combustible gases within the crankcase. The functions of crankcase ventilation are accomplished by devices and passages arranged in what is generally referred to as the breather system.

Breather Systems

Variations in the design and arrangement of breather system parts can be seen if the following descriptions of breather systems for Diesel engines and gasoline engines are studied and compared. Even though all types of breather systems are not described in this chapter, those that are described are representative of many of the systems with which you may come in contact.

GM 12–567 DIESEL ENGINE (fig. 3–24 and 10–13).—The crankcase of the GM 12–567 is ventilated by air drawn through a breather at the accessory end of the engine. The air flows along the entire length of the crankcase, through the oil separator, and then into the blowers.

The blowers draw air from the crankcase through breather connections provided on the intake side of each blower. The oil separator is installed in the breather line that connects to the intake adapter on the blowers. The separator functions to prevent oil mist from being drawn into the blowers. The oil-separating element, which is known by the trade name of Air Maze, is made up of a number of fine-wire screens that are formed into a cylinder. The oil-laden air is drawn through the screens. The

oil is deposited on the screens and drains to the bottom of the separator. The separated oil is returned to the oil pan through a drain pipe which extends below the oil level in the pan to seal against a return flow of air. Harmful vapors which may develop in the crankcase are carried, by the ventilating air, into the blower; they are then forced into the combustion chambers.

GM 268A and 278A DIESEL ENGINES.—The breather systems are basically the same in both of these engines. Atmospheric air for the breather system enters the engine through breathers located in the cylinder-head covers. The blower draws air from the crankcase through the air maze. As in the GM 567, the element of the maze removes the oil from the vapor, thereby preventing oil mist from being drawn into the blower.

In the GM 268A and 278A engines, the air maze element consists of a number of fine steel and copper wire screens (fig. 10–17). These screens separate and collect the oil from the oil-laden vapor as it flows from the crankcase to the blower. The separated oil drains to the bottom of the air maze housing; it is returned to the accessory-drive housing, through a drain tube.

GM SERIES 71 DIESEL ENGINES.—In engines of this type, the areas subject to the accumulation of harmful vapors are ventilated by what is referred to as a continuous, automatic system. This system keeps the crankcase, the gear-train housing, and the valve compartment cleared of vapors which might lead to explosions or otherwise cause damage. The flow of ventilating air through an installation of this type is shown in figure 10–18.

The vapors carried by the ventilating-system air may be discharged either to the atmosphere or to the blower intake, depending upon the type of installation. Discharge to the blower intake is preferable in marine installations.

In installations where contamination of the air surrounding an engine is not a factor, the small vent, or breather pipe (fig. 10–18), connected to the governor-control housing, leads down the side of the engine and

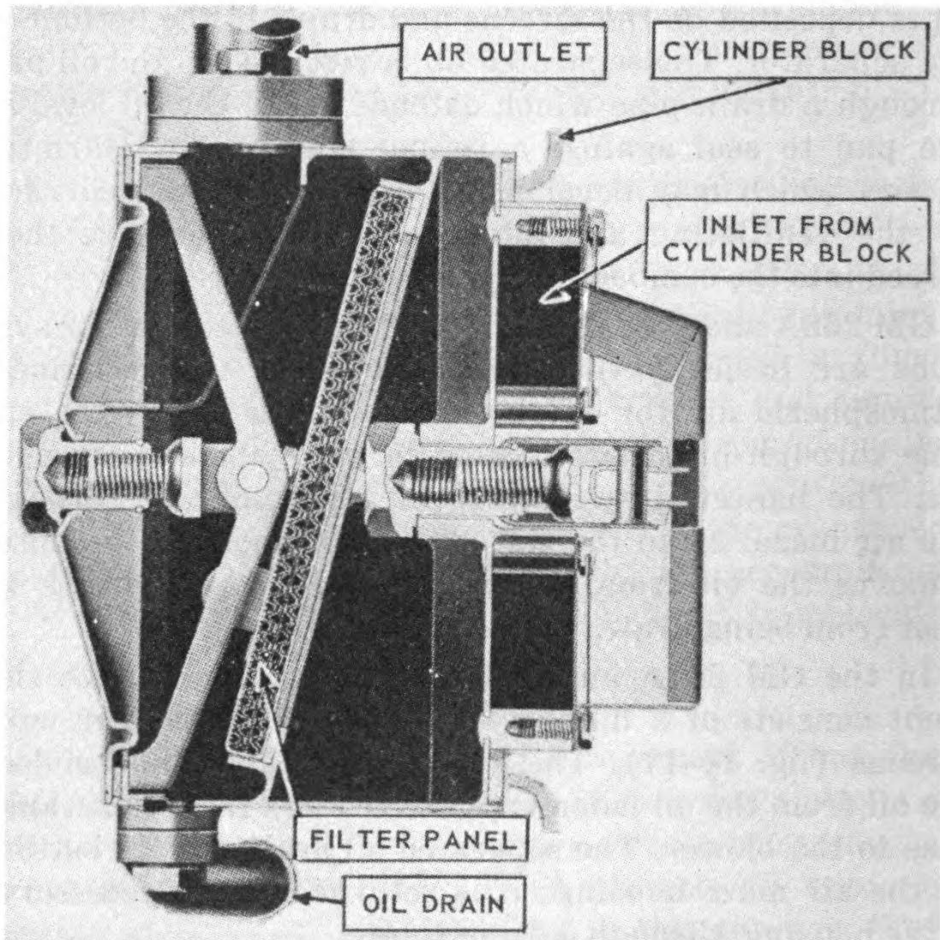


Figure 10–17.—Cross section of an air maze (GM 268A).

vents water vapors and oil fumes to the atmosphere. In cases where contamination of the surrounding atmosphere is a factor, the breather pipe discharges harmful vapors and fumes so that they enter the blower intake.

In the system illustrated in figure 10–18, clean air for ventilation is provided by a small amount of scavenging air which is forced past the oil control piston rings. This air causes a slight pressure to be maintained in the crankcase. Because of the pressure existing in the crankcase, the ventilating air flows up through the flywheel housing (fig. 10–18) into the valve-rocker cover. From the valve compartment, the air flows through a ventilating passage into the governor-control housing. From the gov-

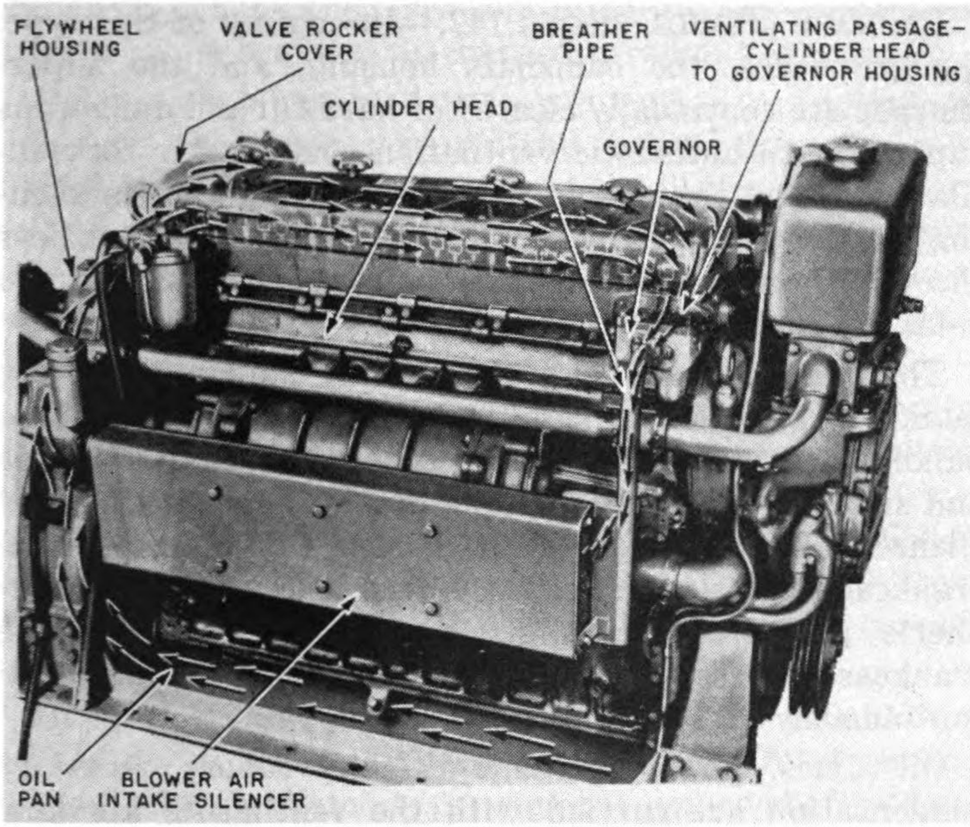


Figure 10–18.—Engine ventilation system (GM 71).

ernor-control housing, the air flows through the breather pipe and into the end of the silencer, from where the air is drawn into the blower.

A continuous circulation of air is maintained in the ventilating system by a slight difference between the pressure existing in the crankcase and that in other parts of the system. While scavenging air is creating a pressure in the crankcase slightly higher than that of the atmosphere, blower action is causing a pressure slightly less than that of the atmosphere in the breather pipe and the valve compartment. As a result, a continuous flow of air is maintained in the ventilating system. Harmful vapors and fumes are removed from the crankcase and the valve compartment, forced into the combustion spaces by the blower, and either burned or discharged through the exhaust system.

PACKARD DIESELS, SERIES 142.—In engines of this type, the crankcase, the camshaft housing, and the supercharger are continually cleared of harmful and dangerous vapors by an automatic ventilation system. Air for ventilation enters the engine through breathers on the camshaft-housing covers. The air flows from the breathers through the valve compartments and down through drain holes in the block into the crankcase.

The crankcase is connected to the supercharger air intake by an external ventilation tube from a crankcase handhole cover, through an oil separator to the air filter and silencer. The flow of intake air through the filter and silencer draws air from the crankcase, and maintains the crankcase pressure at slightly less than normal atmospheric pressure. The slight negative pressure in the crankcase causes the air to enter the breathers and flow continuously into the crankcase.

Oil fumes, blow-by gases, and water vapors caused by condensation are carried with the ventilating air flow into the supercharger, burned in the engine, and expelled through the exhaust.

Any oil drawn into the breather system is separated from the air at the oil separator and drained back into the crankcase.

Ventilation of the supercharger is accomplished by utilizing the slight positive pressure created in the supercharger casing. Pressure in the casing is vented, through a tube, to the crankcase. The resulting air flow (arising from the negative air pressure in the crankcase and the positive air pressure in the supercharger casing) carries any dangerous or contaminated vapors which may develop in the supercharger to the crankcase.

Any water vapor, blow-by gases, and oil fumes and vapor developed in the supercharger, the crankcase, or the camshaft housing of a Packard Diesel, series 142, are carried, by the air in the ventilating system, into the supercharger intake. The supercharger forces the vapors and fumes, along with the intake air, into the combustion

chambers where they are subjected to the combustion process; they are then discharged through the exhaust.

FM OPPOSED-PISTON DIESEL ENGINES.—In engines of this type, the crankcases and the vertical drive are ventilated by means of the suction of the blower. The spaces to be ventilated are placed under slightly less than atmospheric pressure by blower suction through an oil separator. The location and design of the separator depend upon the engine model.

In the FM 38D, the separator is located in the vertical-drive compartment, and is connected to the suction side of the blower by an external pipe. The cylindrical type separator element, consisting of a copper-ribbon screen, collects the oil from the air as it is drawn from the crankcase. This prevents the oil from being carried into the blower.

In the FM 38E, the oil separator is located inside the blower end-cover. Passage to the oil separator from the spaces to be ventilated is through the hollow shafts of the blower impellers. The element of the box-like separator consists of copper gimp.

The element collects oil from the crankcase air as it is drawn through the separator by blower suction. The oil collected by the element drains from both ends of the separator, through the lower compartments of the blower, into the lower crankcase.

GASOLINE ENGINES.—Crankcase ventilation in gasoline engines is similar to that in Diesel engines. Crankcase vapors may be vented to the atmosphere or to the intake system, depending upon the type of installation.

When vented to the atmosphere, crankcase vapors and fumes are removed through a breather tube. One end of the tube is connected to the crankcase, above the oil level. The other end of the tube is located where there is sufficient air flow past the open end to create a low pressure. The pressure differential between the crankcase and the open end of the tube is sufficient to cause an air flow and to remove vapors and fumes from the crankcase. Air

drawn from the crankcase is replaced by air entering the engine through an opening, usually in the valve-mechanism cover.

In gasoline engines which utilize intake-manifold pressure to cause circulation of the ventilating air, the air is drawn directly into the crankcase, generally through an air cleaner or a filter. In some cases, air flows into the crankcase through a vent in the reverse-gear cover. The path of air from the crankcase to the manifold varies in different engines. In some cases, the ventilating air flows from the crankcase through the valve-cover compartment and then to the intake manifold through a tube. In other cases, crankcase air may be vented directly to the intake manifold. The tube which carries crankcase vapors to the manifold usually contains a restriction, or ventilator valve, which regulates the amount of vapor being carried into the manifold. Restricting the flow of vapor into the manifold minimizes the effect of crankcase vapor on the air-fuel ratio of the mixture delivered to the manifold by the carburetor.

Causes and Prevention of Crankcase Explosions

There is little danger of a crankcase explosion, or other troubles caused by vapors within an engine, if the engine is kept in condition, according to the prescribed maintenance program. The ventilating system of an engine greatly reduces the possibility of troubles which might occur because of an accumulation of vapors in the crankcase. Nevertheless, even when an engine is maintained according to prescribed procedures, casualties may occur or conditions may be created which will lead to an explosion in the crankcase of the engine. When such casualties or conditions occur, they are generally due to, or a result of, abnormal operating circumstances or to the failure of a part.

You should be familiar with the possible causes of crankcase explosions so that you can learn how to prevent their occurrence. The importance of knowing what may cause a crankcase explosion and knowing the precaution-

ary or preventative steps required are apparent if the after-effects of an explosion are considered. A crankcase explosion may cause serious injury to personnel and extensive damage to the engine. Such damage as bent connecting rods, a sprung or broken crankshaft, and cracked liners and pistons may be caused by an explosion. Engine-room fires of a serious nature may occur after a crankcase explosion. Some of the factors which may lead to a crankcase explosion are crankshaft-bearing failure, overheated lubricating oil, diluted lubricating oil, damaged or excessively worn liners or piston rings, and cracked or seized pistons.

CRANKSHAFT BEARING FAILURES.—Sparks may be created if a crankshaft bearing disintegrates and causes the journal to make contact with the connecting rod. The heat liberated by the faulty bearing will also help vaporize the lubricating oil. Improper thrust bearing adjustment or worn thrust bearings may permit crank cheeks to strike against a bearing shell, causing sparks. Sparks or excessive heat in the crankcase must not be allowed, as they may, under the proper conditions, set off a crankcase explosion.

The symptoms of impending bearing trouble must be recognized as soon as possible in order that the engine may be stopped before an explosion or damage occurs. Impending bearing failures may be detected by a rise in the lubricating oil temperature, or by a lowering of the lubricating oil pressure. Evidence of an impending bearing failure may be detected, during periodic overhaul, by thorough inspection of the bearing shells and backs for pits, grooves, scratches, and evidence of corrosion. The ability to recognize the symptoms of impending troubles can be acquired only by keen observation during engine operation and by much practical experience.

There are many factors which may cause or lead to bearing failure. Some of the more common causes of bearing failure are metal fatigue, corrosion, abrasives in the oil, and an inadequate supply of oil.

Fatigue failure of a bearing is accelerated by improper installation; and by lack of adequate priming (when applicable) of the lubricating-oil system, prior to starting the engine. Severe overloading or overspeeding increases the possibility of fatigue failure. Operation of an engine at high speeds with one or more cylinders inoperative (due to such factors as clogged injectors or fouled spark plugs) will increase the danger of bearing failure in the case of the inoperative cylinders.

Corrosion, which leads to bearing failure, is caused by the chemical action of oxidized lubricating oils. Oxidation of oil may be minimized by making oil changes at recommended periods and by keeping crankcase temperatures within prescribed limits during engine operation.

Dirt or metallic particles that enter the bearings of an engine either adhere to the bearings during reassembly, or are pumped into the bearings with the lubricating oil. Since abrasives are most likely to enter bearings during a reassembly period, it is of great importance to keep parts and the work space particularly clean during the overhaul period. Of equal importance is the proper servicing of oil filters and air cleaners. (See chapter 14, Maintenance of Engine Systems.)

Crankshaft bearings require an adequate supply of oil for cooling, lubricating, and load-supporting purposes. A bearing will fail if enough oil is not supplied to lubricate it properly. Failure of a bearing to receive an adequate supply of oil does not necessarily mean that the engine oil supply has been consumed or lost through leakage. The supply may be inadequate because of a clogged screen, filter, or strainer. The small, restricted passages in these units may become clogged, stopping or restricting the flow of oil. If prescribed maintenance procedures are not followed during overhaul, particles of lint from unauthorized wiping materials may adhere to parts and cause oil passageways to clog during engine operation.

The maintenance of recommended oil pressure is essential if an adequate supply of oil is to reach all bearing

surfaces. Therefore, the oil pressure gage is the best source of operational information to indicate either the satisfactory performance or the impending failure of a bearing.

Prevention of bearing failure and crankcase explosions involves (1) observance of operating lubricating-oil temperatures and pressures, (2) use of Navy-approved lubricating oils, (3) analyzing the oil at recommended intervals, when possible, to determine its suitability for further use, (4) regular servicing of oil-filtering equipment, (5) frequent sampling of oil drawn from the lowest point in the lubricating-oil system to determine the presence of abrasive materials or water, and (6) the regular use of a purifier if one is provided. Only by following recommended operating and maintenance procedures can the failure of bearings, caused by the use of contaminated oil or an insufficient supply of clean oil, be reduced to a minimum.

OVERHEATED LUBRICATING OIL.—The formation of explosive vapor from lubricating oil is greatly accelerated by a rise in the temperature of the lubricating oil. A rise in temperature may be due to such factors as insufficient circulation of the oil, inadequate cooling of the oil, overloading of the engine, or damaged or excessively worn parts. In addition to creating explosive vapors, the overheating of the lubricating oil has other serious effects. The viscosity of the lubricating oil will be greatly reduced, and the tendency to form gum will be increased. The temperatures of the lubricating oil should be maintained at the value specified in the instruction manual.

DILUTED LUBRICATING OIL.—The dilution of engine lubricating oil with Diesel fuel oil or gasoline will increase the tendency toward vapor formation in the crankcase. This is due to the fact that both of these fuels have lower flash points than lubricating oil. Petroleum products vary greatly in their flash points. (Flash point is the minimum temperature at which a product of petroleum gives off sufficient flammable vapors to ignite, or momentarily

flash.) In general terms, gasolines give off sufficient vapor to ignite at temperatures well below freezing; Diesel fuel oil will give off vapor in sufficient quantities to be ignited, when the oil is heated to about 140° F. On the other hand, a lubricating oil must be heated to a higher temperature (325° F to 580° F, depending on the series and symbol of the oil) before it reaches its flash point. It should be remembered that dilution alone cannot cause a crankcase explosion. It may, however, contribute to making an explosion possible.

Dilution of engine lubricating-oil may be caused by a variety of troubles. In general, dilution of the lubricating oil may be a result of worn or stuck rings, worn liners or pistons, fuel leaks, and leaky nozzles or injectors (on Diesels). It should be remembered that, even though an engine is in good condition, dilution will occur during continuous engine operation at low speeds and under idling conditions. Under these conditions of operation, dilution occurs as a result of the blow-by of unburned fuel particles which accumulate in the combustion spaces.

You may already be familiar with the preventive measures necessary to avoid some of the troubles which lead to the overheating or dilution of engine lubricating oil. Considerably more study and practical experience may be required, on your part, however, before you learn how to prevent the occurrence of all conditions which lead to the overheating or dilution of lubricating oil.

DAMAGED OR EXCESSIVELY WORN LINERS OR PISTON RINGS.—If the cylinder liners or the piston rings are in poor condition, they will permit blow-by. Unburned fuel, the gases of combustion, and possibly some of the flame will be blown into the crankcase. The effect of the hot gases is to vaporize the lubricating oil. If any flame is allowed to pass the rings, it may ignite the vapors and cause a crankcase explosion. Only in cases of extreme wear, however, will there be the probability of such an occurrence. Some of the factors which cause excessive wear of cylinder liners and piston rings are foreign par-

ticles in the cylinder, improper or inadequate lubrication, improper cooling, and improper fit of mating parts. If an engine is maintained and operated according to prescribed procedures, the above-mentioned troubles are not likely to occur.

CRACKED PISTON.—A cracked piston will allow the gases of combustion and spurts of flame to reach the crankcase. This is perhaps the most frequent cause of crankcase explosions. Cracked pistons result from one or more of the following: obstruction in the cylinder, loose piston, faulty nozzle spray, and faulty piston-cooling. A cylinder may be obstructed by a broken valve-head, a broken nozzle tip, and water. Careless maintenance procedures may result in foreign objects being left in a cylinder when the engine is overhauled. A loose piston is generally the result of an excessively worn liner or of a combination of a worn piston and a worn liner.

A distorted fuel-spray pattern will cause unequal temperatures on the piston, which often result in cracks. This type of trouble can generally be prevented by properly maintaining the nozzles. Cooling of the piston is accomplished (1) by the fresh charge of air blown over the piston crown, (2) by conduction of heat through the piston rings to the cylinder wall, and (3) by oil sprayed or conducted over the underside of the piston crown. If the oil flow is restricted, the underside of the piston accumulates deposits which will lower the rate of heat transfer. Whenever pistons are removed, the underside of the crowns should be thoroughly cleaned.

SEIZED PISTON.—When a piston seizes, a great amount of heat is liberated. The excess heat causes some of the lubricating oil to vaporize and the danger of a crankcase explosion is increased. The sparks which may be created when a piston seizes may fall into the crankcase and further increase the possibility of an explosion.

The seizing of pistons can be prevented by operating and maintaining an engine so that the causes of piston seizure are eliminated. Piston seizure may be the result

of insufficient clearances, excessive temperatures, or inadequate lubrication.

Installation of pistons with insufficient clearances will result in piston seizure. Piston-to-cylinder clearance must always be checked before final assembly. The proper value can be found in the appropriate maintenance manual. If the clearances are insufficient, do not complete assembly with the thought in mind that sufficient clearances will be gained by "wearing in."

Piston seizure resulting from overheating can be avoided by operating the engine within the prescribed temperature limits. An adequate flow of oil to the cylinder surface and proper cooling are required, if the pistons are to be prevented from seizing. Thus, it is necessary to maintain the parts of the lubricating system and the cooling system in the best possible condition.

SUMMARY

Lubricating systems of the pressure type are found in most of the modern, internal combustion engines. Pressure lubricating systems generally include pumps, strainers, pressure-regulating valves, filters, bypass valves, and coolers, in addition to the necessary tubing and passages. Such a system may be classified as the wet- or dry-sump type, depending on the oil-supply arrangement; and as the shunt, sump, or bypass type, depending on the filtering system used.

Even though the lubricating systems of various engines differ in some respects, all the systems are quite similar with respect to oil flow. In general, the pump draws oil from the source of supply (oil pan, sump, or separate tank) and forces the oil through a strainer, a filter, and a cooler before the oil enters the engine. Upon entering the engine, the oil generally flows into an oil manifold, which may be either a passage in the block or frame or a separate line suspended in the crankcase. The manifold, usually parallel to the crankshaft, supplies oil to all parts of the engine which require lubrication.

From the manifold, oil flows to the main bearings either through separate lines or through drilled passages in the crankshaft. Oil for the lubrication of camshaft bearings may flow from the main bearings, through drilled passages; or from the manifold, through separate passages or lines. Passages drilled from the main journal through the webs of the crankshaft direct oil to the connecting-rod journals and bearings. In most cases, the connecting rods are drilled so that oil can flow to the piston-pin bearings and to the underside of the piston.

In cases where the connecting rods are not drilled, separate lines are provided to the piston-pin bearings and to the pistons, for lubrication and cooling. Piston-pin bearings and the undersides of the pistons also receive lubrication from oil that is thrown by the rotating parts of the engine. The piston rings and cylinder walls also are lubricated in this manner. Timing gear-trains and timing chains are usually lubricated, directly or indirectly, from separate oil lines or through passages in the gears of the camshaft gear-train. In some engines, lubrication of timing mechanisms is accomplished by the return flow of lubricating oil from other sources, such as the valve mechanism and the blower. Ordinarily, the return of oil from the various parts of the engine to the oil supply is by gravity. In some engines, it is necessary to use a scavenging, or return, system to draw oil from spaces where gravity flow is not possible; and to return the oil to the supply reservoir, for recirculation.

Ventilation of the engine crankcase is essential for efficient and safe engine operation. Unless the crankcase of an engine is properly ventilated, harmful vapors will accumulate in the crankcase. These vapors come primarily from two sources.

Some of the vapors are formed when the lubricating oil comes in contact with the hot, internal surfaces of the engine. Vapors so formed are explosive. These vapors must be removed from the crankcase; otherwise, a local hot spot within the engine might ignite the charge.

Vapors may also accumulate in the crankcase because of the blow-by past the pistons. Blow-by occurs when the piston is compressing the air or the fuel-air charge, and during the power event. In gasoline engines, the fuel from the blow-by of the fuel-air charge will tend to dilute the lubricating oil. In all engines, products of combustion escape past the piston rings, into the crankcase, during the power event. These products of combustion contain a great deal of water vapor, which is condensed when it comes in contact with a cool surface. Such condensation causes corrosion; and contaminates the lubricating oil, often forming an emulsion.

The crankcases of engines are ventilated to prevent the accumulation of vapors which might lead to an explosion in the crankcase, or which might cause dilution and emulsification of the lubricating oil or corrosion within the system. Ventilation may be directly to the atmosphere or to the engine intake system. The latter method is preferred in marine installations, where the engine is usually located in a compartment, because venting of the vapors to the atmosphere would seriously contaminate the air and create a fire hazard.

QUIZ

1. What type of pump is used in engine lubricating-oil systems?
2. Name two types of pressure-control devices that may be incorporated in a lubricating-oil pump.
3. How does a control device regulate lubricating-oil pressure?
4. Why are two elements included in some lubricating-oil strainers?
5. Is oil flow to the engine stopped when a simplex strainer becomes clogged? Why?
6. Name two types of elements that are used in metal-edge type strainers.
7. How is the element of a metal-edge type strainer cleaned, without connections being broken or the flow of oil being interrupted?
8. Screen-type strainers are usually located on which side of the pressure pump?
9. Why is Fuller's earth not permitted in filters approved for use in engine lubricating-oil systems?
10. Name three types of lubricating-oil filtering systems.
11. In what type of lubricating-oil filtering system does all of the oil discharged by the pump flow directly to the engine through a strainer, a filter, and a cooler?
12. How does a sump-type filtering system differ from a shunt-type system?
13. With what type lubricating-oil-filtering system is it possible to filter the oil when the engine is not operating?
14. In a lubricating-oil system in which the filtering system is of the sump type, what is the path of oil from the oil supply to the engine inlet? (Indicate path by listing main components in the proper order.)
15. Name the two types of filtering systems in which oil flows directly from the filter back to the sump.
16. What limits the amount of oil which flows through the filter of a bypass-type filtering system?
17. By listing the main parts of the system in their proper order, trace the path of oil through the external section of a lubricating-oil system which includes a shunt-type filtering system.
18. Name two ways in which oil for cooling may be supplied to the pistons of an engine.
19. What is the first part to which lubricating oil usually flows after it enters the engine?
20. When is use made of the auxiliary pump which is incorporated in some lubricating systems?
21. How is oil supplied to the crankpin bearings, in most engines?

22. How are the crankshaft bearings lubricated in small gasoline engines which have no lubricating oil system?
23. List four undesirable conditions which may occur if the crankcase of an engine is not properly ventilated.
24. In gasoline engines, unburned fuel may blow-by the compression rings, enter the crankcase, and dilute the lubricating oil. This situation is less likely to occur in a 2-stroke cycle engine. Why?
25. How are oil particles sometimes prevented from entering the blowers of engines in which the crankcase is ventilated to the intake system?
26. What happens to the harmful vapors which are vented from the crankcase to the intake system?
27. How may a crankshaft-bearing failure lead to a crankcase explosion?
28. What is the best source of information when you are checking an operating engine for symptoms of an impending bearing failure?
29. Why will fuel-diluted lubricating oil contribute more readily to conditions which may cause a crankcase explosion, than will oil which is not diluted by fuel?

CHAPTER 11

ENGINE COOLING SYSTEMS

A great amount of heat is generated within an engine during operation. Combustion produces the greater portion of this heat; however, compression of gases within the cylinders and friction between moving parts add to the total amount of heat developed within an engine. Since the temperature of combustion alone is about twice that at which iron melts, it is apparent that, without some means of dissipating heat, an engine would operate for only a very limited time.

Of the total heat supplied to the cylinder of an engine by the burning fuel, only one third, approximately, is transformed into useful work; an equal amount is lost to the exhaust gases. This leaves approximately 30 to 35 percent of the heat of combustion which must be removed in order to prevent damage to engine parts. Heat which may produce harmful results is transferred from the engine through the mediums of water, lubricating oil, air, and fuel.

As a Fireman, you learned that heat transfer may take place by radiation, conduction, and convection. (See *Fireman,* NavPers 10520–A.) All three methods of heat transfer are utilized in keeping engine parts and fluids (air, water, fuel and lubricating oil) at safe operating temperatures. For example, the heat of combustion radiates to the surfaces of the combustion space. The heat is then conducted from the surfaces of the combustion space,

through such parts as the piston crown and piston rings, to the cylinder walls. From the cylinder walls the heat is transferred to the water of the cooling system, where heat transfer by convection takes place.

Part of the heat of combustion which radiates to the piston crown is conducted through the pistons to the lubricating oil, from which the heat may be transferred to the cooling system. A small portion of heat is continuously radiated to the atmosphere from the external surfaces of the heated engine parts.

Even though air, lubricating oil, and water are the primary mediums for engine cooling, the cooling effect of fuel should not be overlooked. Of the various cooling mediums, the water of the cooling system removes the greater portion (approximately one fourth) of the heat generated by combustion. The balance of the heat (usually less than 10 percent) is removed from the engine by the lubricating oil, the fuel, and the air.

REASONS FOR COOLING AN ENGINE

If the heat lost through cooling could be turned into work by an engine, the output of the engine would be almost doubled. However, the loss of valuable heat is necessary in order for an engine to operate efficiently. Without proper temperature control, the lubricating-oil film between moving parts would be destroyed, proper clearance between parts could not be maintained, and metals would tend to fail.

To Maintain Adequate Lubrication

The need for maintaining a film of lubricating oil on pistons, cylinder walls, and the contacting surfaces of other moving parts of an engine has been discussed in chapter 9 of this course. The oil film must be maintained if adequate lubrication is to be provided. The formation of such an oil film depends, to a large degree, on the viscosity of the oil. If the engine cooling system did not

keep the engine temperature below a specified level, there would be a reduction in viscosity to a point where the oil film might be destroyed. This would result in insufficient lubrication, and consequent excessive wear of parts which make rubbing or rolling contact. Also, the heat absorbed by lubricating oil from the combustion process and from friction in bearings must be removed to retard oxidation of the oil and resulting sludge formation.

The prevention of overheating is generally thought of as the primary function of an engine cooling system; however, it is possible that a cooling system might remove too much heat. If an engine is operated at too low a temperature, condensation takes place, causing acids and sludge to form in the lubricating oil. Also, cylinder temperatures must be maintained high enough to minimize the condensation of corrosive gases on the cylinder walls. Excessively low operating temperatures will increase ignition lag, which causes detonation. Thus, it is apparent that the cooling system of an engine must maintain the operating temperatures within a specified range. The range of operating temperatures for a given engine are to be found in the applicable manufacturer's instruction manual.

To Prevent Excessive Variation in Dimensions

In addition to lubricating-oil troubles, other difficulties may occur if the cooling system does not maintain operating temperatures within a specified range. Great differences between operating temperatures at varying loads cause, through contraction and expansion, excessive changes in the dimensions of engine parts. These excessive changes also occur when there are large differences between the cold and the operating temperatures of the parts. These changes in dimensions result in a variation in clearances between the moving parts. Under normal operating conditions, these clearances are very small; any variation in the dimensions of the moving parts may cause insufficient clearances and subsequent inadequate lubrication, increased friction, and possible seizure.

To Retain the Strength of Metals

By removing heat from an engine, the cooling system also aids in preventing the deterioration of the metal in the engine parts. If the parts, such as liners, pistons, valves, and bearings are allowed to overheat, the tensile strength will be materially reduced, thereby accelerating wear and increasing the probability of failure. If overheating is sufficiently severe, the affected part will melt.

High temperatures change the strength and physical properties of the various metals used in an engine. For example, if a cylinder head is subject to excessively high temperatures, the tensile strength of the metal is reduced; the probability of fracture is thereby increased. Such high temperatures also cause excessive expansion of the metal, which may result in shearing of the cylinder-head bolts.

TYPES OF COOLING SYSTEMS

In a marine engine, the system which functions to keep engine parts and fluids at safe operating temperatures may be of the open or closed type. In the open system, the engine is cooled directly by salt water. In the closed system, fresh water (or antifreeze) is circulated through the engine. The fresh water is then cooled by salt water. In marine installations, the closed system is the type commonly used; however, some older marine installations use a system of the open type.

The cooling systems of Diesel and gasoline engines are similar mechanically and in function performed. For these reasons, much of the information which follows is applicable to the cooling systems of both types of engines.

The Open Cooling System

The term "open" is used because the liquid used for cooling purposes in the open system is drawn directly from the water in which the boat or ship operates, is passed through the system, and is then discharged overboard. The open system is sometimes identified as the "raw" water system, because the water is untreated and generally contains contamination, whether the water is

drawn from the sea, a lake, or a river. However, since the majority of the Navy's boats and ships operate in sea water, the open-type cooling system is generally referred to as the "sea" or "salt" water system, regardless of the system's source of water.

In open cooling systems, the sequence of parts and passages through which the water flows may vary slightly between engines. In a typical open system, the salt water is drawn from the sea chest or scoop, through sea valves and a strainer, by a pump; it is then discharged through the lubricating-oil cooler. In some installations the strainer is located in the pump discharge line.

The oil cooler acts as a heat exchanger, with the heat from the oil circulating through the cooler being transferred to the water passing through the cooler. Thus, the

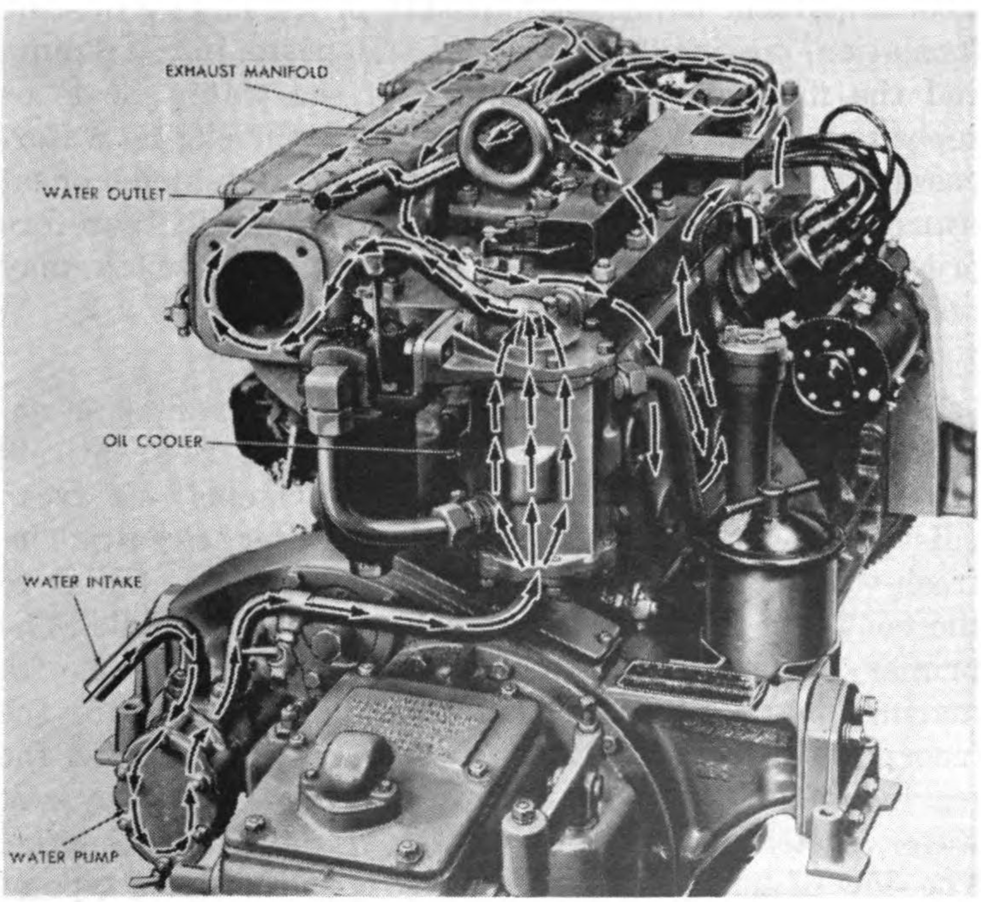


Figure 11—1.—An open cooling system (Chrysler M—8).

temperature of the oil is lowered and the temperature of the intake water is raised before the water passes into the engine cooling-passages.

From the cooler, the water passes through water jackets and passages within the engine, cooling such parts as the cylinder liners, the block, and the head or heads. After cooling the various parts of the engine, the water passes through the exhaust-silencer water jackets and then discharges overboard. In some engines, water flows through the exhaust-silencer water jackets before it flows through the engine passages. Thus, the heat from the lubricating oil and the exhaust gases is utilized to raise the temperature of the engine intake-water. The path of cooling water through one arrangement of an open cooling system is shown in figure 11–1.

The open cooling system has several disadvantages, the most important being the exposure of the engine to scale formation, marine growth and dirt deposits in the piping, and the fluctuating temperature of sea water. Scale or deposits not only restrict water flow in the engine water-passages; they also act as insulation and hinder heat transfer to the cooling water. Scale and deposits therefore prevent adequate cooling of engine parts, which may result in serious difficulties.

The Closed Cooling System

The closed-type water cooling system of a marine engine, in most cases, actually consists of two entirely separate circuits (sometimes called systems)—a fresh (distilled)-water circuit and a salt-water circuit. The fresh-water circuit is a self-contained system, similar to the cooling system in the engine of an automobile. The primary differences between the fresh-water circuit of a marine installation and that of an automobile are the incorporation of a cooler, rather than a radiator, in the marine installation; the carrying away of heat by salt water, instead of air, in the case of the marine engine. The flow of liquid through the two circuits of one type of closed cooling system is illustrated in figure 11–2.

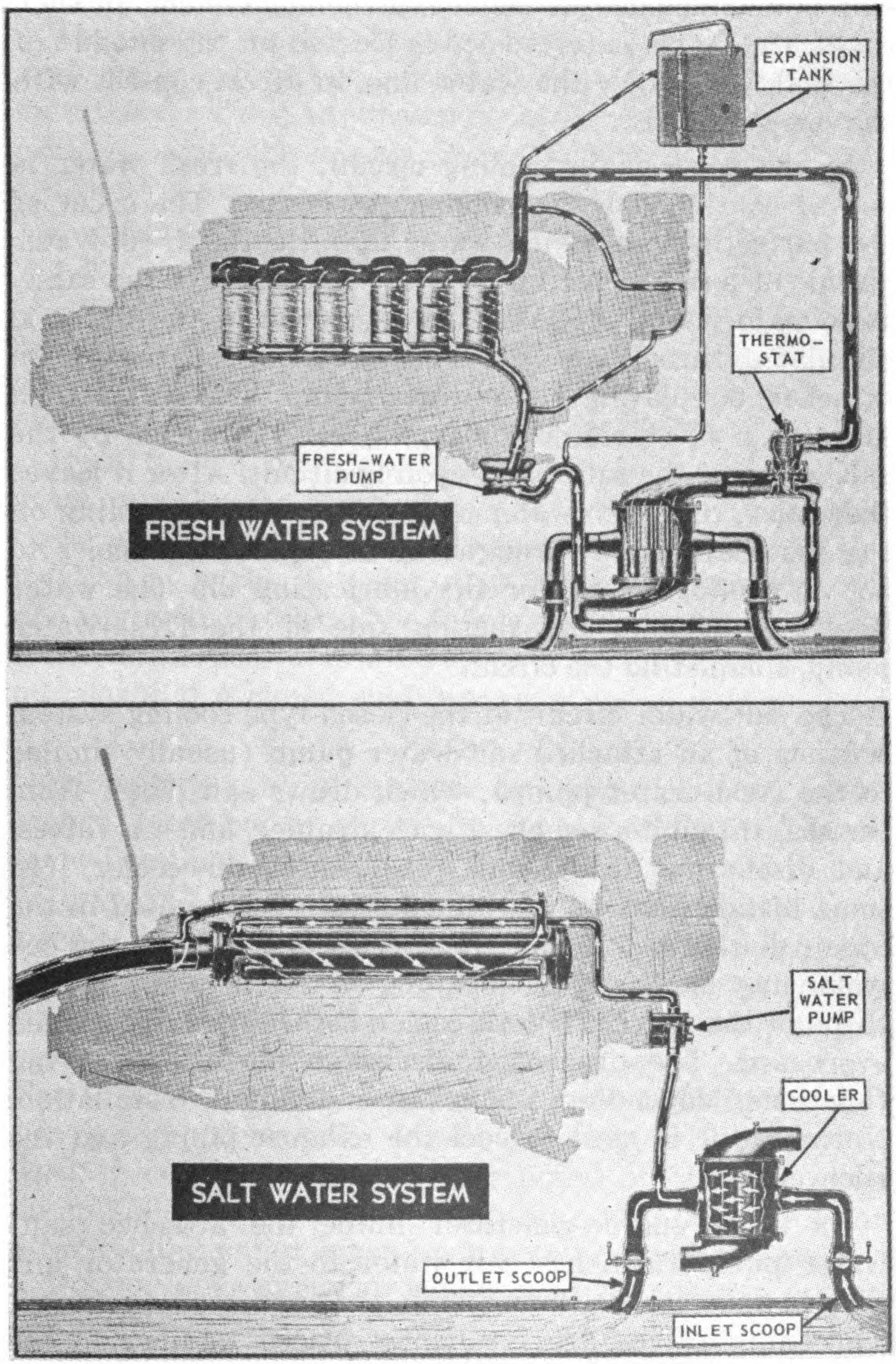


Figure 11—2.—A closed-type cooling system with fresh- and salt-water circuits.

In some marine installations, a separate salt-water circuit is not included in the closed cooling system. In such cases, the fresh-water cooler is located on the outside of the hull, well below the water line, in direct contact with the sea water.

In the fresh-water cooling circuit, the fresh water is reused continuously for cooling the engine. The order of the parts through which water flows in the fresh-water circuit of a closed cooling system is not always the same. In a majority of the installations, however, the water is circulated throughout the engine cooling spaces by an attached circulating fresh-water pump. The water then flows to a fresh-water cooler, where it is cooled by the salt water of the salt-water cooling circuit. After it leaves the cooler, the fresh water may or may not, depending on the installation, go through the lubricating-oil cooler to act as cooling agent for the lubricating oil. The water finally returns to the suction side of the fresh-water pump, completing the circuit.

The salt-water circuit of the closed-type cooling system consists of an attached salt-water pump (usually similar to the fresh-water pump), which draws salt water from the sea, through a sea chest with strainer, and sea valves, and discharges it through the fresh-water cooler. (In some installations an additional strainer is located in the pump discharge.) From the fresh-water cooler, the sea water may or may not, depending on the installation, pass through the lubricating-oil cooler before it is discharged overboard. The overboard discharge performs varying functions, depending upon the individual installation. Normally, it is used to cool the exhaust piping and the silencer.

On some engine-generator units, the attached salt-water pump furnishes salt water to the generator air-coolers and returns the water to the overboard discharge. Throttling valves are frequently placed in lines to the fresh-water cooler and the generator air-coolers to control the flow of water through these heat exchangers.

PRINCIPAL PARTS OF A CLOSED COOLING SYSTEM

The closed cooling system of an engine may include such parts as pumps, coolers, engine passages, water manifolds, valves, expansion tank, piping, strainers, connections, and instruments. Some of these parts and their location on one type of engine are shown in figure 11–3. The schematic diagrams in figures 11–4 and 11–5 show the parts and the path of water flow in the fresh- and sea-water circuits of one arrangement of a closed cooling system. Note that two pumps, one for each bank of cylinders, are provided; and that, in this case, the lubricating-oil cooler is located in the fresh-water circuit.

Even though there are many types and models of engines used by the Navy, the cooling systems of most of these engines include the same basic parts. Design and location of parts, however, may differ considerably from one engine to another. The following discussion points out some similarities and differences to be found in the various parts of a closed engine-cooling water system.

Pumps

All engine cooling systems are provided with an attached fresh-water pump. In some installations, a detached auxiliary pump is also provided.

PURPOSE.—The attached pump is used to keep the water circulating through the cooling system. Since attached pumps are engine driven, it is impossible for cooling water to be circulated in the engine after the engine has been stopped; or in the event the attached pump fails. For this reason, some engines are equipped with an electric-driven (detached) auxiliary pump, which may be used if either the fresh-water pump or the salt-water pump fails. An auxiliary pump may also be used as an after-cooling pump, when an engine has been secured.

DIFFERENCES BETWEEN FRESH- AND SALT-WATER PUMPS.—The pumps used in the fresh- and salt-water circuits of an engine cooling system may, or may not, be of the same type. In some cases, the pumps in both circuits are

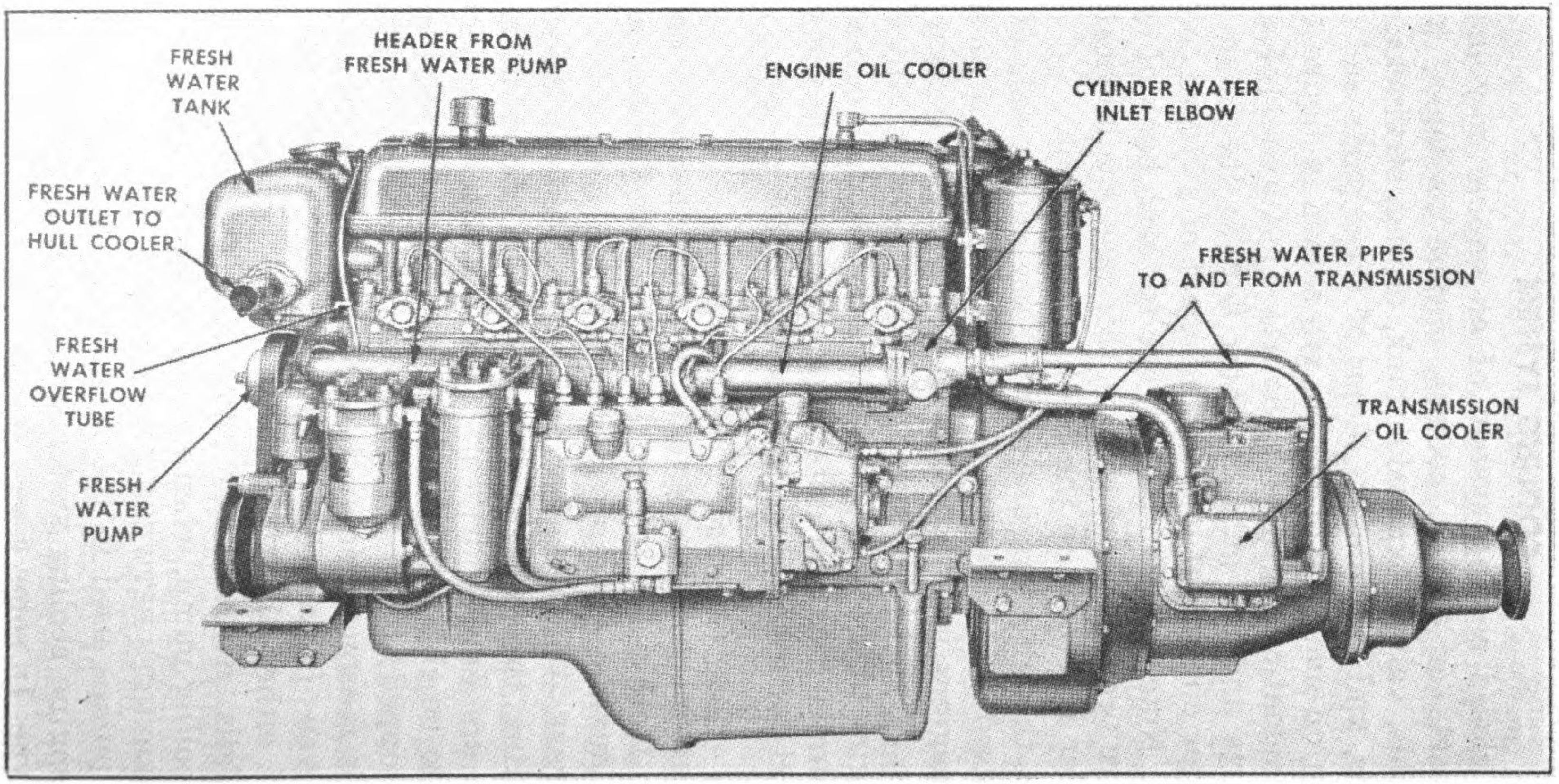


Figure 11—3.—Parts of a cooling system (Gray Marine, Six-D427).

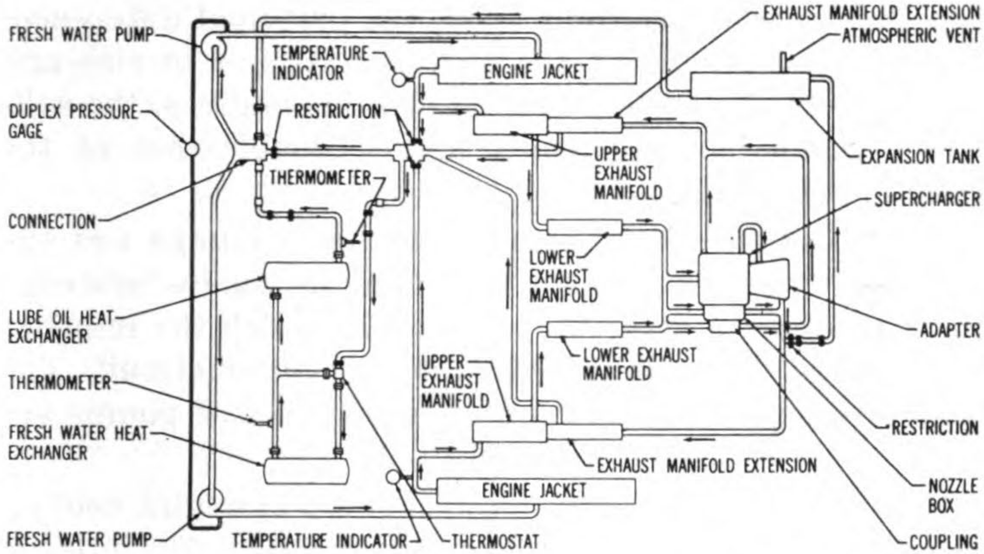


Figure 11—4.—Fresh-water circuit of a closed cooling system (Packard Diesel, series 142).

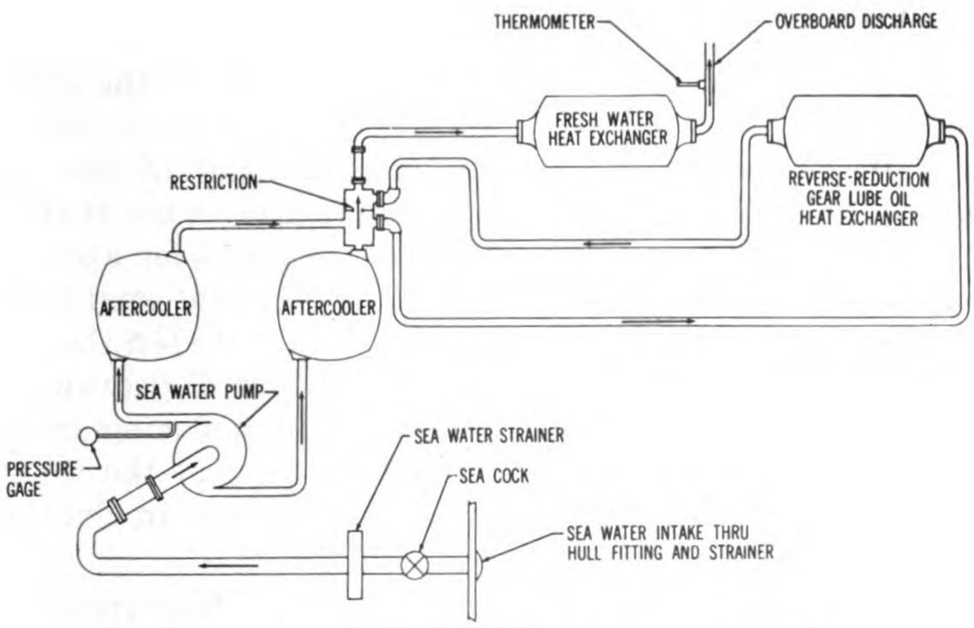


Figure 11—5.—Salt-water circuit of a closed cooling system (Packard Diesel, series 142).

identical. In other cases, where pumps are of the same type but where variations exist, the principal differences between the pumps of the two circuits are in size and capacity. In the cooling system of some engines, the salt-water pump has a capacity almost double that of the fresh-water pump.

TYPES.—Centrifugal pumps and gear pumps are the principal types of pumps used in engine cooling systems. In some cases, a rotary-type pump in which the impeller has flexible vanes is used in the salt-water circuit. The basic principles of operation of these types of pumps are given in *Fireman,* NavPers 10520–A.

Centrifugal pumps are more common in engine cooling systems than pumps of other types, particularly in large Diesel engines. Centrifugal pumps are of many varied types. They may be separately driven or attached to the engine, single or double suction, open or closed impeller, reversible or nonreversible, etc. In all centrifugal pumps, however, water is drawn into the center of the impeller and thrown at high velocity into the casing surrounding the impeller, where the velocity decreases and pressure increases correspondingly.

In all such pumps, sealing devices, usually of the stuffing-box type, are provided to prevent leakage of water, oil, grease, or air around the impeller shaft of the impeller shaft sleeve (when one is used to protect the shaft).

Generally, the clearances between the impeller and the casing must be small in order to reduce the internal leakage. Wear rings are frequently employed between the impeller and the casing so that the desired small clearances, when lost, may be regained readily by replacing these rings. The rings are designed to take most of the wear. The routine maintenance of pumps is covered in chapter 15 of this course.

LOCATION AND METHOD OF DRIVE.—Depending upon the engine and the type of installation, the location of the pumps and the method of drive will vary. Note that in the upper illustration of figure 11–2 the fresh-water pump

is mounted on the bottom of the lower crankcase at the supercharger end of the engine. In this case, the pump is gear-driven by a drive gear on the crankshaft; the pump is driven at one and one-half times engine speed. The salt-water pump of the same engine (lower illustration, figure 11–2) is mounted on the supercharger housing. In this case, the salt-water pump is driven from the supercharger driveshaft through a coupling shaft; it operates at crankshaft speed.

In the engine shown in figure 11–3, we find that the fresh-water pump is located in a housing mounted on the bottom of the water (expansion) tank. The pump is pulley-driven, with a V-belt, by the crankshaft. The salt-water pump (not shown in fig. 11–3), used only for exhaust cooling in the Gray Marine Six-D427, is mounted on the front of the engine and is belt-driven by the crankshaft. A phantom view of the salt-water pump, showing the impeller and the bearings, is shown in figure 11–6.

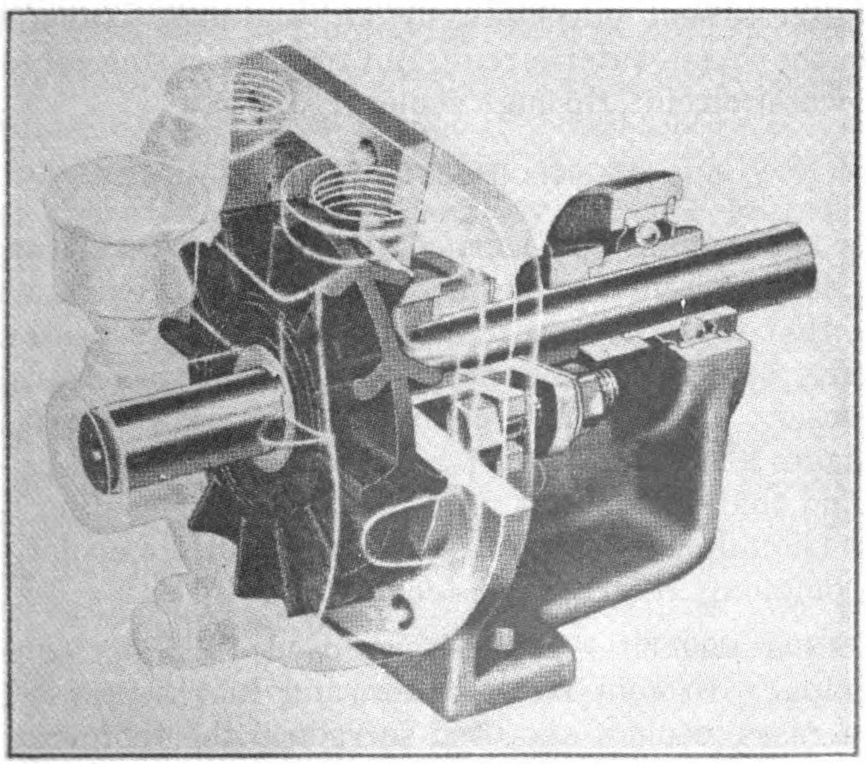


Figure 11–6.—Phantom view of a rotary type salt-water pump (Gray Marine Six-D427).

In some models of the FM opposed-piston engine, the fresh-water pump and the salt-water pump are located on opposite sides of the engine, at the control end. The pumps of the FM engine are driven by the lower crankshaft, through the flexible-drive coupling (fig. 6–9 and fig. 6–13), which also drives the fuel and lubricating pumps and the governor. In the case of the GM 16–278A, the cooling-system pumps are mounted on opposite sides of the blower housing and are driven by the crankshaft, through the accessory-drive gear train (fig. 6–5 and fig. 6–8). The fresh-water pump on the GM 6–71 is mounted on the front end of the blower (fig. 6–2) and is driven by the lower blower rotor shaft, through a coupling. The examples given here are only a few of many which could be given to illustrate the variations in pump location and method of drive. Regardless of location and drive, the pumps function, in all cases, to keep the water circulating through the system so that heat may be dissipated and operating temperatures kept within safe limits. Most of the excess heat developed by an engine is transferred from the fresh-water circuit and the lubricating oil to the salt-water circuit, through coolers.

Coolers (Heat Exchangers)

As a Fireman, you learned that devices that transfer heat from one fluid to another are called heat exchangers; also, that these devices may be used as either heaters or coolers, and that the same device can be used for both purposes. In internal combustion engines, heat exchangers are used primarily for cooling. For this reason, we find that the devices used in engines for cooling a hot fluid (liquid or gas) by transferring heat to a cooler fluid are commonly referred to as coolers.

FLUIDS COOLED.—Coolers are used in Navy engines principally to cool fresh water and lubricating oil. In some cases, coolers are used to reduce the temperatures of engine intake-air and generator cooling-air. In most marine engine installations, the fresh water of the engine

cooling system is cooled by salt water. Lubricating oil and air may be cooled by salt water or by fresh water, depending on the installation. Thus, on the basis of the fluids cooled, you will encounter fresh-water coolers, lubricating-oil coolers, and air coolers. All coolers operate on the same principle; coolers used on various installations and for the cooling of various fluids may differ, however, in appearance and in details of design.

CLASSIFICATION (GENERAL).—Coolers may be classified in several ways: by the relative direction of flow of the two fluids (parallel flow, counterflow, and cross-flow types); by the number of times either fluid passes the other fluid (single-pass and multi-pass types); by the path of heat (indirect-contact, or surface, type and direct-contact type); and by the general construction features of the unit (shell-and-tube type and jet, or mixer, type). The coolers used in the cooling systems of engines are commonly identified on the basis of construction features. In some cases, the number of times one fluid passes the other fluid is also used in identifying the type of cooler.

TYPES.—On the basis of classification by construction features, a cooler is either of the shell-and-tube type or the jet type. In jet-type coolers, the hot and cold fluids enter the unit, are mixed, and are then discharged as a single fluid. Since this feature is not desirable in engine cooling, the coolers used with engines are of the shell-and-tube type. In a shell-and-tube cooler, the hot and cold fluids are prevented from mixing by the thin walls of the tubes of the element.

The shell-and-tube type is a general classification which includes all coolers in which the two liquids are prevented from mixing. Modifications of the shell-and-tube cooler have resulted in two other types of coolers: the strut-tube cooler; and the plate-tube cooler. These coolers are of the shell-and-tube type in that the fluids are prevented from mixing; however, due to design features, the coolers used in engines are commonly identified as being either the strut-tube type or the plate-tube type.

The cooling systems of many engines are equipped with coolers of the SHELL-AND-TUBE type. Coolers of this type are frequently referred to as Ross-type coolers. Shell-and-tube coolers are used for the cooling of lubricating oil and of fresh water. Coolers used for the cooling of lubricating oil are somewhat smaller than those used to cool water. One model of a shell-and-tube cooler is shown in figure 11–7.

The shell-and-tube cooler consists principally of a bundle (bank, nest) of tubes, encased in a shell. The cooling liquid generally flows through the tubes; and the cooled liquid enters the shell at one end, circulates around

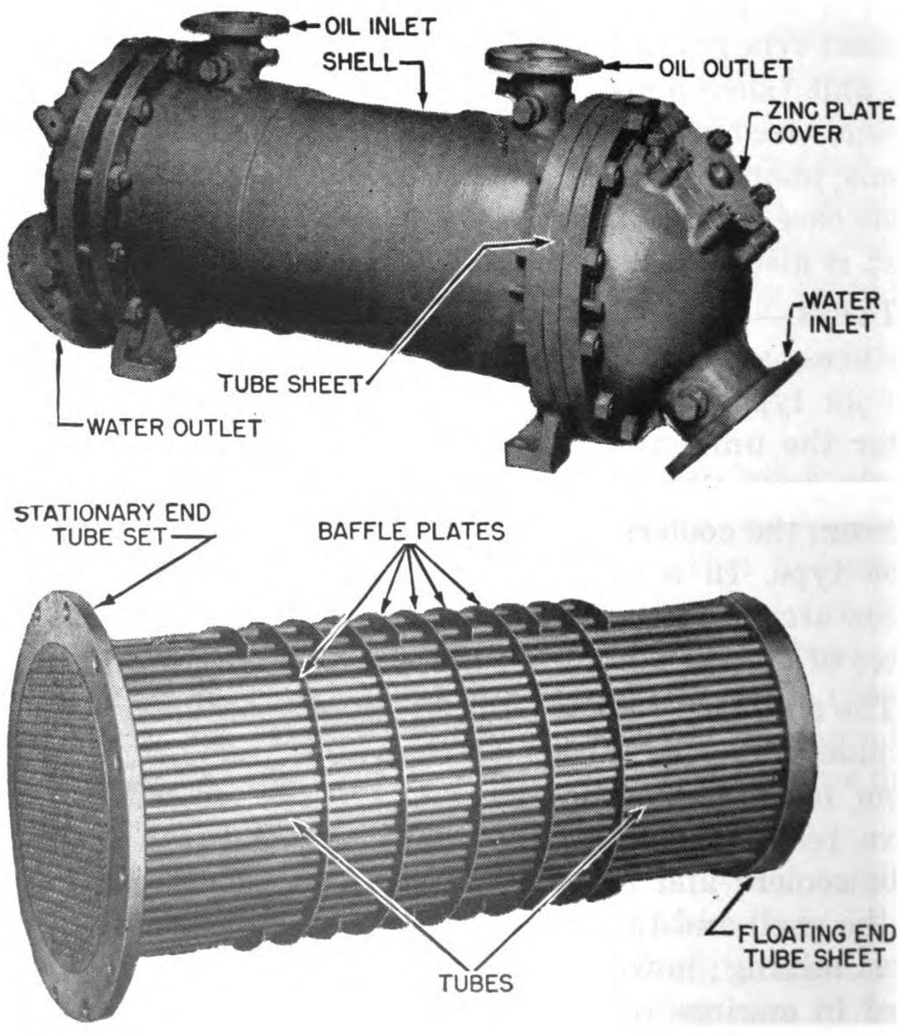


Figure 11–7.—Shell-and-tube cooler of a Cooper-Bessemer GSB-8 engine.

the tubes, and is discharged at the opposite end of the shell. In some cases, however, the cooling liquid flows through the shell and around the tubes; and the cooled liquid passes through the tubes.

The tubes of the cooler are attached to the tube sheets at each end of the shell. This arrangement forms a tube bundle which can be removed from the shell, as a unit. The ends of the tubes are expanded to fit tightly into the holes in the tube sheets; they are flared at their outer edges to prevent leakage.

One tube sheet and a bonnet are bolted to the flange of the shell. This sheet is referred to as the stationary-end tube sheet. The tube sheet at the opposite end "floats" in the shell. This feature allows for expansion of the tube bundle. Packing rings, which prevent leakage past the floating-end tube sheet, are fitted between the shell flange and the bonnet, at the floating end. The packing joint allows for expansion and prevents the mixing of the cooling liquid with liquid to be cooled inside the shell, by means of a leak-off, or lantern, gland which is vented to the atmosphere. The details of the floating end of a shell-and-tube cooler are shown in figure 11–8.

Transverse baffles are arranged around the tube bundle in such a manner that the liquid is directed from side to side as it flows around the tubes and through the shell. The deflection of the liquid ensures the maximum cooling effect. Several of the baffles serve as supports for the bank of tubes; these baffles are of heavier construction than those which only deflect the liquid.

The flow of the liquid in the tubes is opposite to that of the liquid flow in the shell. On this basis, the cooler could be classified as of the counter-flow type. Since heat transfer is through the walls of the tubes; and since cooling liquid enters one end of the cooler, flows directly through the tubes, and leaves at the opposite end, however, the cooler could be more precisely classified as a single-pass, indirect-type cooler.

The majority of the coolers used in the cooling systems

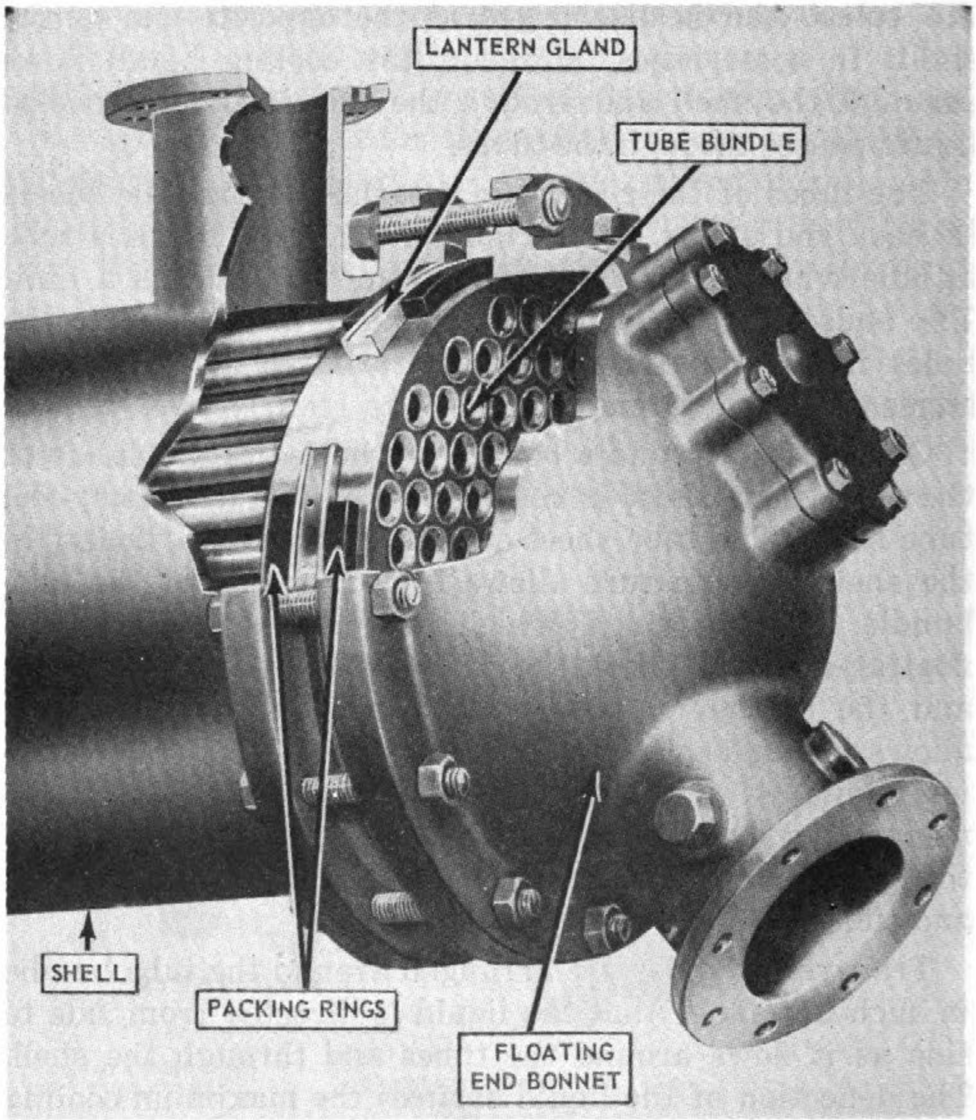


Figure 11—8.—Floating end of a shell-and-tube cooler (Cooper-Bessemer, GSB-8).

of marine engines are of the STRUT-TUBE type. The strut-tube cooler has an advantage over the shell-and-tube cooler in that it provides considerable heat transfer in a smaller and more compact unit. On the other hand, the shell-and-tube cooler, while larger for an equivalent amount of heat transfer, has an advantage over the strut-tube cooler in that it is able to withstand a higher degree of scaling and larger foreign particles without clogging the cooling system. Strut-tube coolers are commonly re-

ferred to as Harrison-type coolers; however, manufacturers other than Harrison produce coolers of the strut-tube type. The term radiator is also used, sometimes, to identify coolers with strut-tube construction.

There are many different designs of strut-tube coolers. The tube assemblies of two of these coolers, and the type of tube construction in each, are illustrated in figures 11–9 and 11–10.

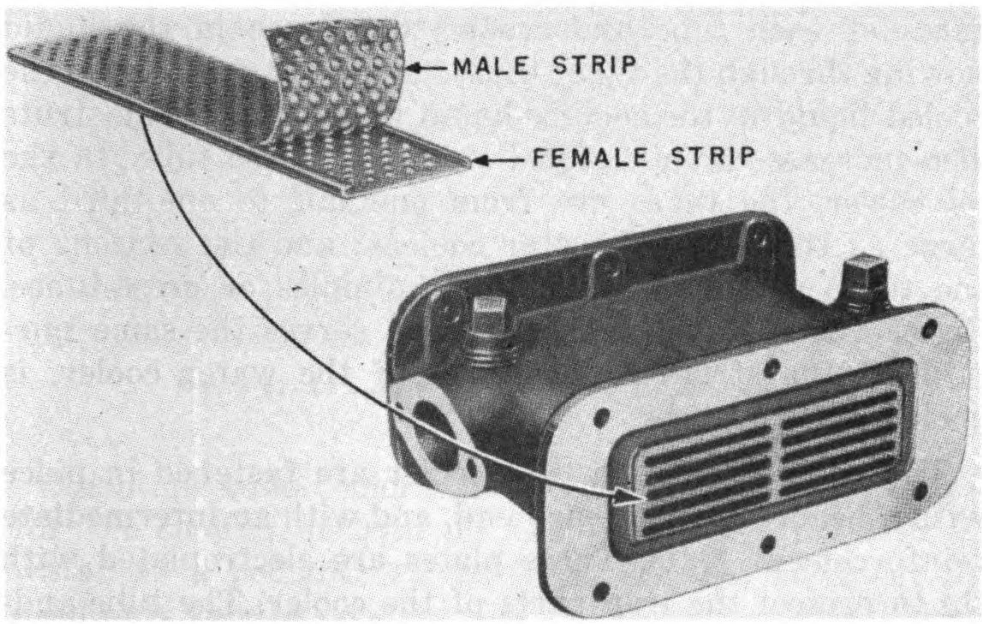


Figure 11–9.—Tube assembly of a strut-tube water cooler (Harrison).

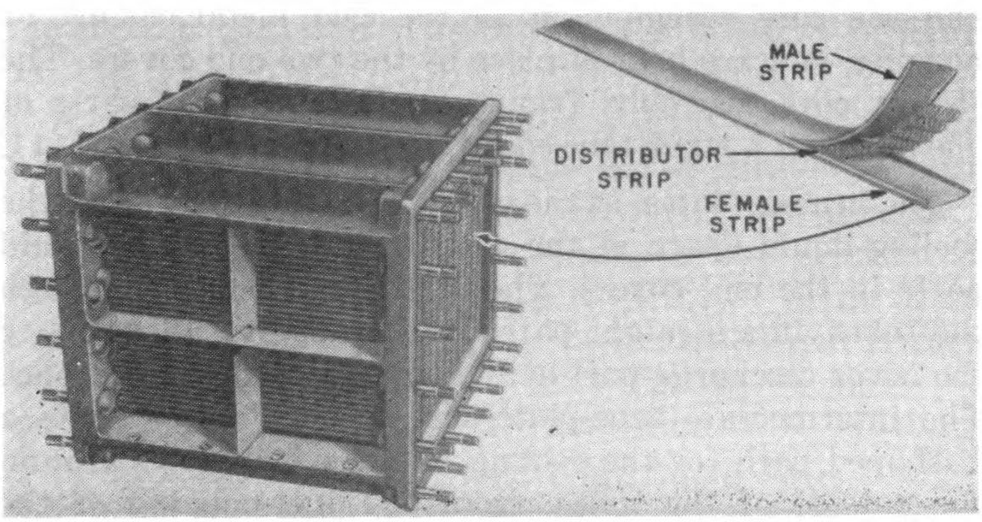


Figure 11–10.—Tube assembly of a strut-tube lubricating-oil cooler (Harrison).

Strut-tube coolers are used for the cooling of water and of lubricating oil. Water coolers and oil coolers differ principally in design and in size of the tubes. (See fig. 11–9 and 11–10.) Each of the tubes in both oil coolers and water coolers are composed of two sections, or strips. In the strut-tube water cooler, both sections of each tube contain either a series of formed dimples or cross-tubes brazed into the tubes. These "struts" (sometimes referred to as baffles) increase the inside and outside contact surfaces of each tube and create turbulence in the liquid flowing through the tube; thus, the heat transfer from the cooled liquid to the cooling liquid is increased. The struts also increase the structural strength of the tube. In the oil cooler, the tubes are from one-half to one-third as large as the tubes of water coolers; and the sections of the tubes do not contain either dimples or cross-tubes. Instead, a distributor strip, which serves the same purpose as the struts in the tubes of the water cooler, is enclosed in each tube.

The tubes of a strut-tube cooler are fastened in place with a header plate at each end, and with an intermediate reinforcement plate. These plates are electroplated with tin to protect the iron parts of the cooler. The tube-and-plate assembly (sometimes called the tube bundle or the core assembly) is mounted in a bronze frame. The frame and the core assembly fit in the cast metal casing, or housing, and are held in place by the two end covers. The casing, core assembly, frame, covers and other parts of one model of a strut-tube cooler are shown in figure 11–11.

The header plates, at the ends of the tubes, separate the cooling-liquid space in the casing from the cooled-liquid ports in the end covers. The cooled liquid flows through the tubes, in a straight path, from the cover inlet-port to the cover discharge-port at the opposite end of the cooler. The intermediate tube-plate acts as a baffle to create a U-shaped path for the cooling liquid, which flows around the outside of the tubes, from the inlet-opening of the casing to the discharge-opening.

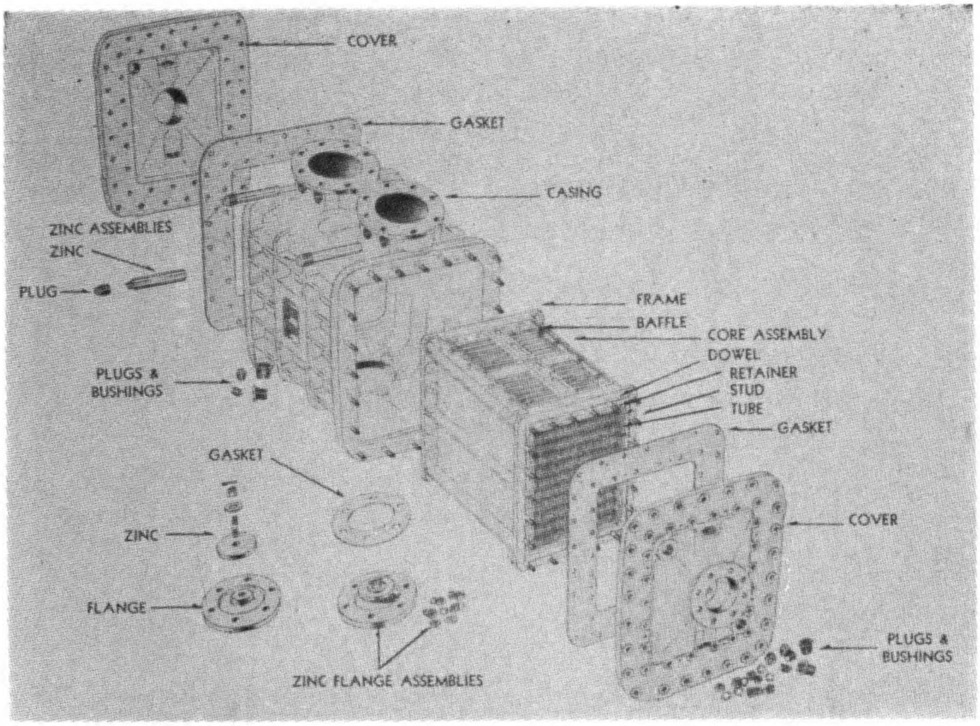


Figure 11—11.—Parts of a strut-tube cooler (Harrison).

Shell-and-tube coolers and strut-tube coolers are used for the cooling of both oil and water, usually with sea water as a coolant; PLATE-TUBE COOLERS, however, are used only for the cooling of oil. Sea water or fresh water may be used as the cooling liquid in plate-tube coolers, depending on the installation. An exploded view of one model of a Harrison plate-tube cooler is shown in figure 11–12.

A plate-tube cooler consists of a stack of flat, oblong, plate-type tubes which are connected in parallel with the oil supply and enclosed in a cast metal housing. Each tube of a plate-tube cooler consists of two sections, or stampings, of copper-nickel. A distributor strip is enclosed in each tube. Several tubes are assembled to form the cooling element, or core, of the cooler. A plate-type core and tube construction are shown in figure 11–13.

In a plate-tube cooler, the cooling liquid flows through the casing and over the tubes. The heated oil flows through the tubes. The tubes in the core assembly are so spaced

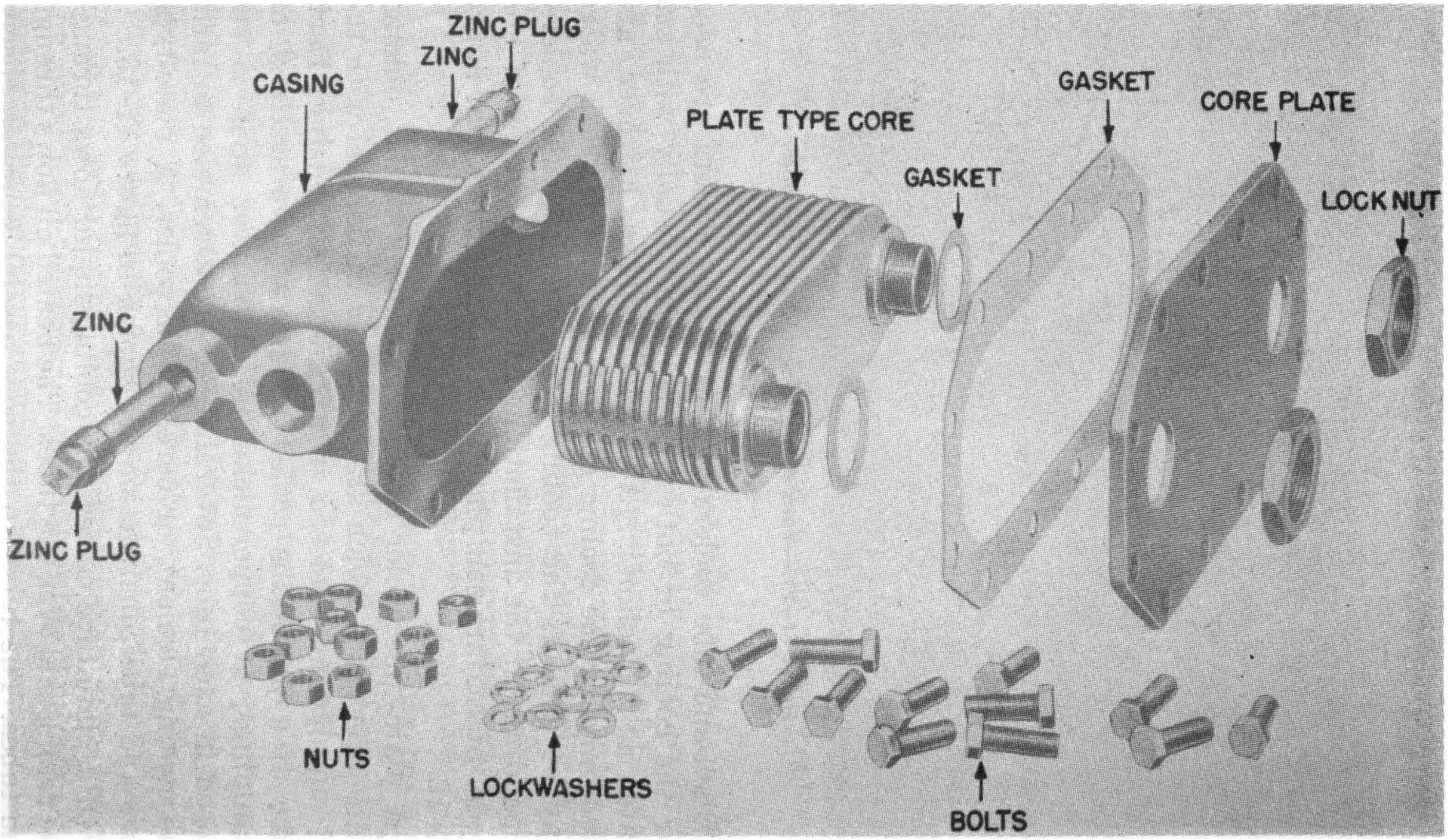


Figure 11–12.—Plate-tube cooler (Harrison).

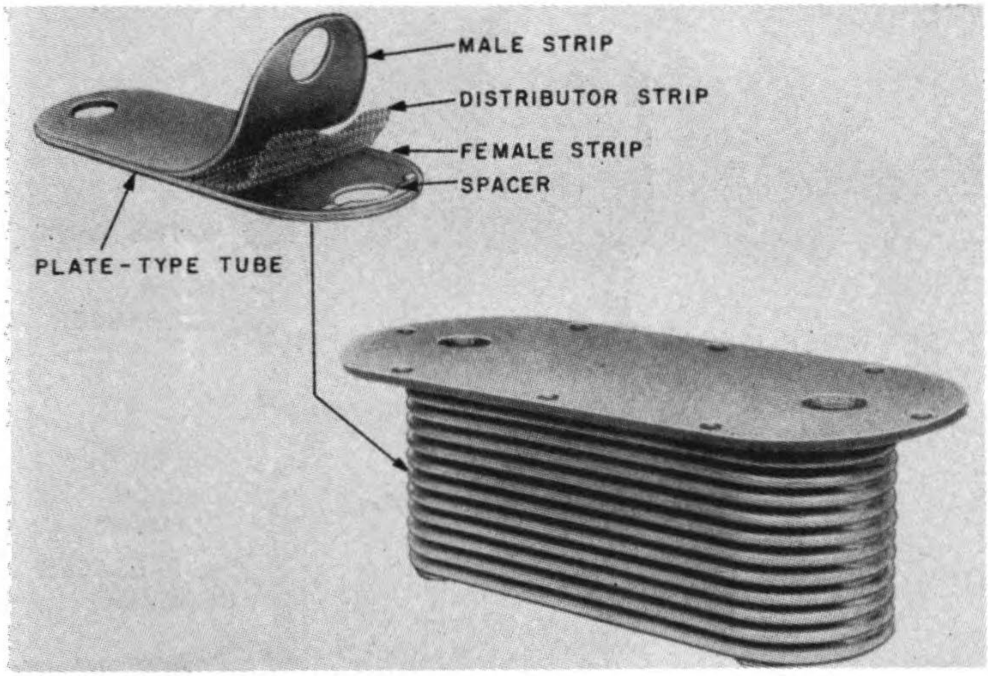


Figure 11–13.—Plate-type core and tube construction (Harrison).

that the cooling water circulates freely over their external surfaces.

LOCATION.—The location of coolers will vary, depending on the engine and the fluid cooled. Some coolers are attached; others are detached. An example of a detached fresh-water cooler is shown in figure 11–2. The fresh-water cooler used with the engine shown in figure 11–3 is also detached. In some cases, the fresh-water cooler is located on the outside of the hull, well below the water line. When so located, coolers are frequently referred to as "outboard," "keel," or "hull" coolers.

Examples of variations in the locations of attached fresh-water coolers and lubricating-oil coolers can be seen in figures 11–1, 11–3, 11–14, and 11–15. Note that the lubricating-oil cooler of the open system (fig. 11–1) is attached to the engine block and that cooler is located between the salt-water intake and the exhaust-manifold water jacket. The engine shown in figure 11–3 utilizes two lubricating-oil coolers: one for engine oil; the other for transmission oil. Fresh water serves as the cooling

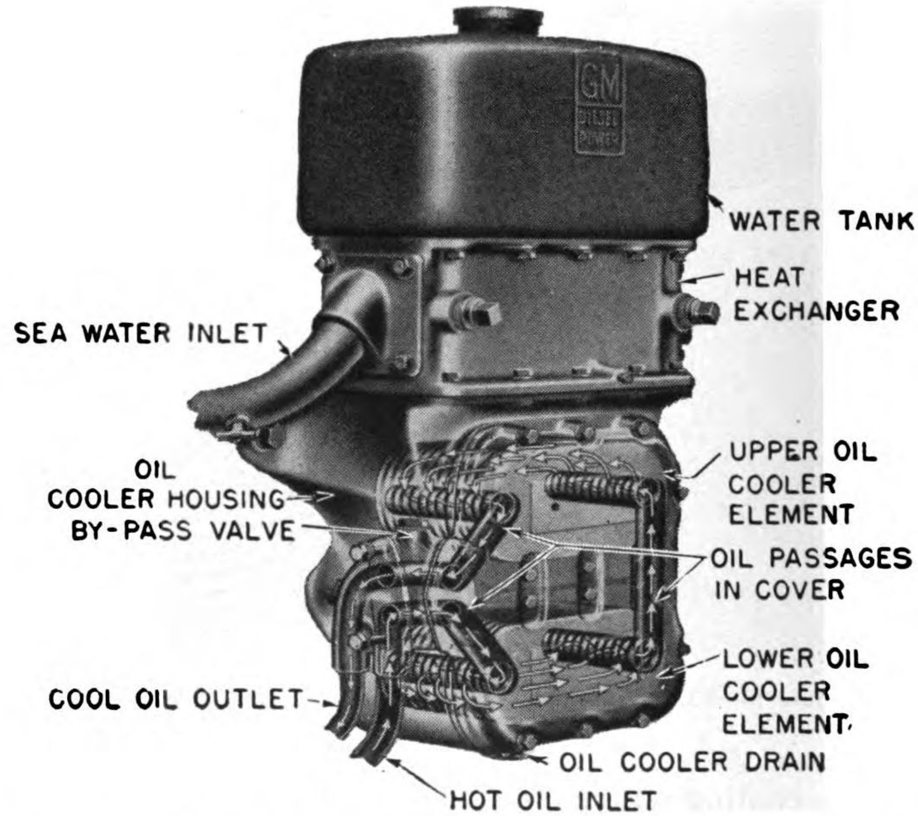


Figure 11–14.—Location of coolers and other cooling-system components of GM series 71 engines.

liquid in both coolers. The location of the fresh-water coolers and the lubricating-oil coolers of the GM series 71 engines (fig. 11–14) is representative of cooler-location in many small diesel engines. How the location of the coolers in a medium-sized diesel differs from that in smaller engines is shown in figure 11–15.

The coolers discussed up to this point have been those used in lowering the temperature of fresh water and of lubricating oil. In some engines, the temperature of the supercharged intake-air is also reduced. If the temperature of this air, which is heated by compression within the supercharger, is reduced, the size of the air charge entering the cylinder during each intake event and the power output of the engine will be increased. Coolers used for lowering the temperature of the intake air are of the strut-tube type and operate on the same principle as cool-

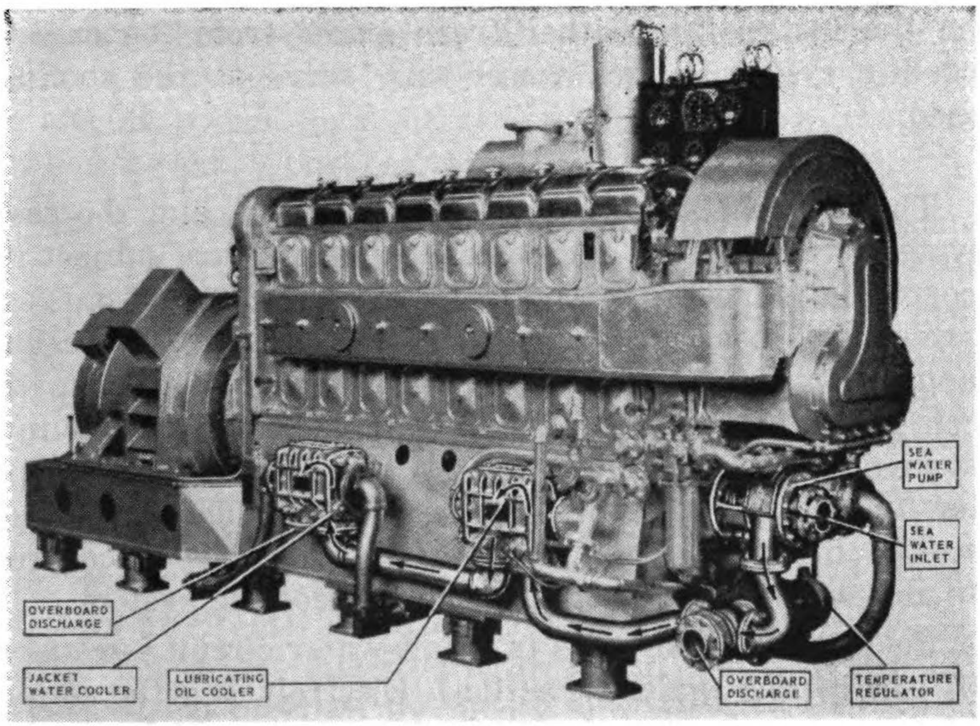


Figure 11—15.—Location of coolers and other cooling-system components of GM 8—268A engines.

ers used for the cooling of fresh water and of lubricating oil. Air coolers, used to cool intake air, sometimes called after-coolers, are located between the supercharger and the intake manifold. The heated air from the supercharger passes through the tubes, where the heat is transferred to the cooling water flowing around the outside of the tubes. Cooling water is generally from the sea-water circuit, but may be from the fresh-water circuit.

The engine cooling system is also used to cool the air around some engine-generator sets. Generators, unlike internal combustion engines, cannot be cooled by liquids. If a generator develops more heat than can be removed by the surrounding air, a supply of cool air must be provided to remove the excess heat. Where generator air-cooling is necessary, an air cooler is provided in a closed air circuit. The heated air from the generator is forced through the cooler, where the temperature is reduced; the air is then recirculated to the generator. Depending

on the installation, either fresh water from the engine cooling system or sea water may serve as the cooling medium.

Zincs

The internal surfaces of both the fresh- and the sea-water circuits of an engine cooling system are subject to corrosion. Since such corrosion may lead to casualties, preventive measures must be taken to control corrosion and to minimize its effects. Information dealing with corrosion control in the fresh-water circuit of a cooling system is included under Fresh-Water Treatment in chapter 14, Maintenance of Engine Systems. The following section in this chapter deals only with corrosion control in the sea-water circuit of an engine cooling system.

Corrosion of the parts in a salt-water circuit is caused by electrolysis (galvanic action). Electrolysis is the action of minute uncontrolled electrical currents which are developed by the action of sea water on metals. When two dissimilar metals are immersed in an electrolyte (such as sea water), an electric current flows from one metal to the other, through the electrolyte. The metal from which the current is flowing suffers rapid corrosion; the metal toward which the current is flowing is protected from corrosion.

Some metals react very rapidly to galvanic action, while such action on other metals is barely noticeable. Lead, copper, tin, and brass are least affected by electrolysis; the ferrous metals are affected in varying degrees. Of the metals which are highly susceptible to galvanic action, zinc is commonly used for replaceable electrodes in sea-water circuits.

When clean zinc is installed in the sea-water side of such as a cooler, the current developed by the action of the sea water on the dissimilar metal flows from the zinc to the adjacent metal of the cooler; thus the metal of the cooler is protected from corrosion caused by galvanic action. In other words, zincs do not prevent electrolysis but, instead, provide a surface for the attack of galvanic

action; other metals in the salt-water circuit are then not affected appreciably. Zincs centralize electrolysis within a circuit, providing a surface which can be replaced after it has served its purpose.

It is necessary to provide for the delivery to a ground of the stray electrical currents generated by electrolysis. In most cases, grounding is accomplished in engine cooling systems by metallic contact between the zincs and the housing of the cooler. This allows grounding to the source of water, as the electricity passes through the engine, the propeller shaft, and the propeller.

Zincs are used to protect all units which are cooled by sea water; they may be installed at various points in the sea-water circuit. The use of zincs is commonly associated with coolers. As shown in figures 11–7, 11–11, and 11–12, the location of zincs in coolers will vary. In all cases, a zinc is provided at the sea-water inlet of the cooler; in many cases, one is also located on the discharge side. The location of the zincs in the salt-water side of one type of cooler is shown in figure 11–16.

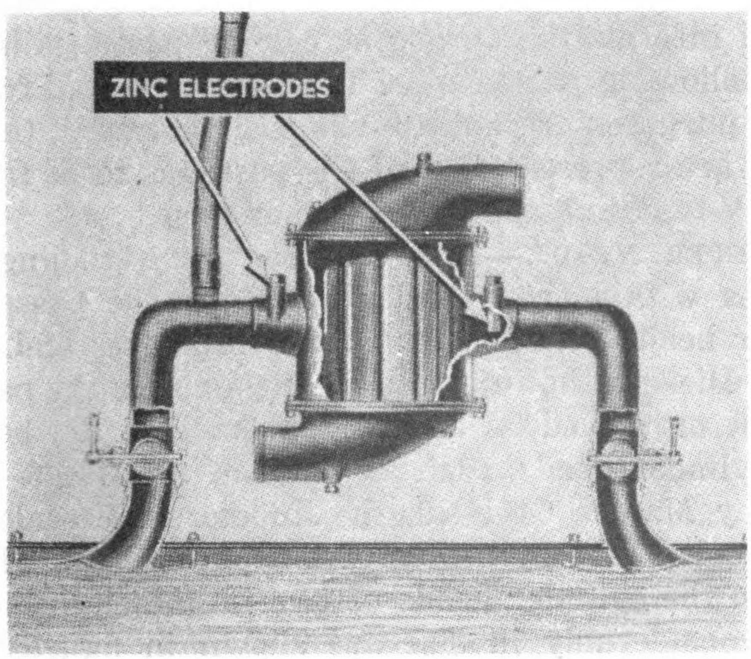


Figure 11–16.—Location of zincs in a salt-water circuit.

The shape of zinc to be used depends on the application and, in some cases, on the location of the zinc. In strut-tube and plate-type coolers, the electrodes are generally in the form of bolts, called zinc PENCILS. In shell-and-tube coolers, zincs are in the form of PLATES. If the sea water is circulated through the shell, the plates are fastened inside of the shell. If the sea water flows through the tubes, the plates are located inside the header or bonnet and are fastened to a cover plate (fig. 11–7).

Engine Water Passages

The form, location, and number of cooling passages within an engine vary considerably in different engines. The form which a cooling water passage must have and its location are controlled by many factors, some of which are size of engine, cycle of operation, and cylinder arrangement. Many of the water passages to be found in various engines have been illustrated and mentioned earlier in this course in connection with engine parts. (See fig. 3–1, 3–12, 3–14, 3–15, 3–16, 3–17, 3–18, 3–19, 3–23, 5–1, and 5–20.) A recheck of these figures will reveal some of the differences in the form and the location of the water cooling passages in different engines. Additional information on engine cooling passages is given in the following paragraphs. The examples used for illustrative purposes are not all-inclusive; however, those described are representative of the passages to be found in in-line, V-type, and opposed-piston engines.

CYLINDER HEADS.—Most engines have cooling-water passages within the cylinder head(s). The passages in cylinder heads generally surround the valves and, in the case of Diesels, the injectors. In most cases, the passages are cast or drilled as an integral part of the head. In some cylinder heads, such as those of the GM 6–71 and the Gray Marine 64–HN9, the injectors are sealed in a water-cooled tube by means of a neoprene seal. The passages in the cylinder heads of two in-line engines which differ considerably in size are shown in figures 11–17 and 11–18.

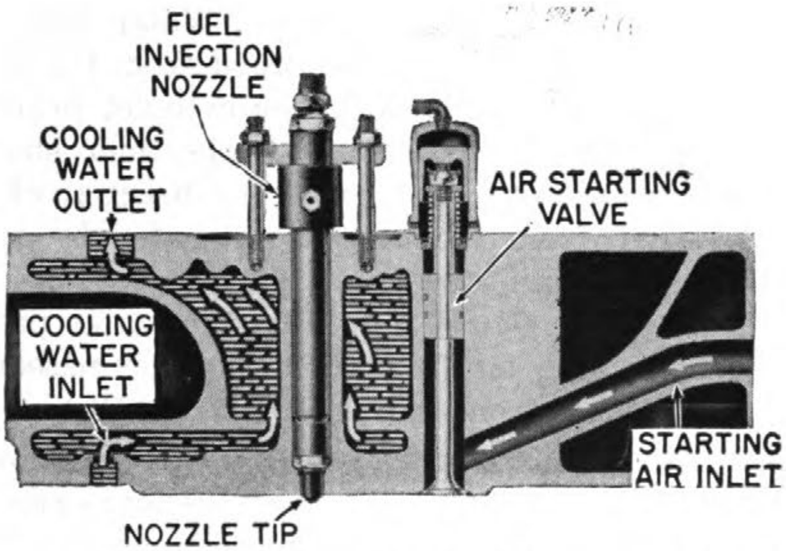


Figure 11–17.—Water passages and path of flow in cylinder head of a Cooper-Bessemer GSB-8 engine.

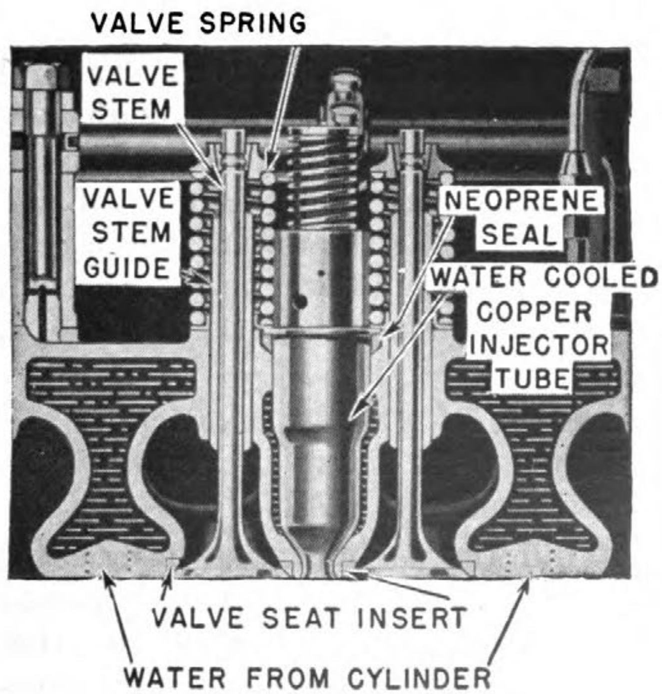


Figure 11–18.—Water passages in cylinder head of a Gray Marine engine.

CYLINDER LINERS OR BLOCKS.—The passages in the cylinder head(s) receive water from a jacket or from passages, either of which may be an integral part of the cylinder liners or the cylinder block. Water flow to the cylinder head is almost always upward from the liner or block. (See fig. 3–1 and 3–15.) The cylinder head illustrated in figure 11–17 is used with the liner shown in figure 3–15. In each of these figures, the direction of circulation of water from the liner is indicated by arrows. The cylinder head in figure 11–18 is of the type used with the block shown in figure 3–1. Note the water passages from the block (12, fig. 3–1), and the inlet passages in the head for water from the block (fig. 11–18.).

WATER MANIFOLDS AND JACKETS.—The location and form of the water passages in a V-type engine are basically the same as those found in an in-line engine. Differences which exist are generally due to the cylinder arrangement. The location and form of these passages at one point in a V-type engine are shown in the cross-sectional view of the GM 16–278A (fig. 11–19).

Note the location (in fig. 11–19) of the two fresh-water manifolds. These manifolds receive water from the fresh-water pump. From the manifolds, the water flows into cylinder-liner passages; and then through the cylinder-head passages. From the cylinder-head passages, the water flows through the water jackets of the exhaust elbows and of the exhaust manifold. The water is forced from the exhaust-manifold water jacket, through a cooler, before the water is recirculated through the system by the pump.

Another example of a water manifold is identified in figure 3–1. Figure 5–20 shows the water jacket around the exhaust manifold of a GSB–8.

Because of differences in engine design, the location and form of the cooling passages in an opposed-piston engine will differ, to a degree, from those in other types of engines. The lack of cylinder heads eliminates some of the passages common to engines of the in-line and V-types.

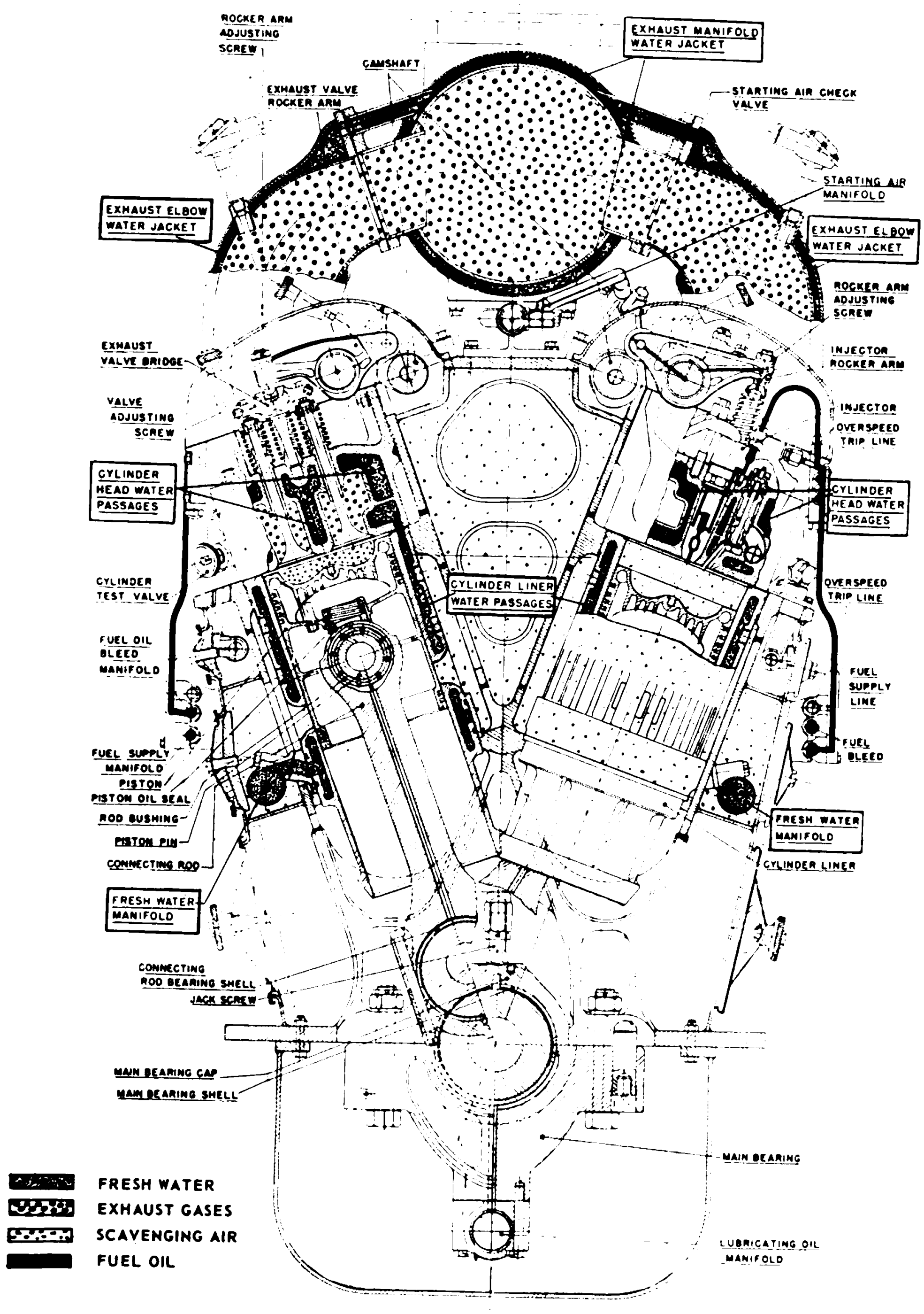


Figure 11–19.—Water cooling passages in a V-type engine.

While differences of a minor nature exist in the passages of different types of engines, the cooling passages of all engines are similar in many respects. Some of the ways in which the passages of an opposed-piston engine are similar to those of other types of engines are shown in figure 11–20.

Note that in the FM engine the exhaust manifolds are encased in water jackets similar to those of the GM 16–278A and the GSB–8. The liner passages of the FM 38 are similar to those found in other types of engines. The location of the water header (manifold) differs in various engines. In such engines as the GM 16–278A (fig. 11–19), and the GSB–8, the water manifold receives water from the pump. In these engines, water from the manifold flows through the liner- and head-passages and then on to cool the exhaust manifold before it flows through the cooler and back to the pump. In the FM 38D, the water from the

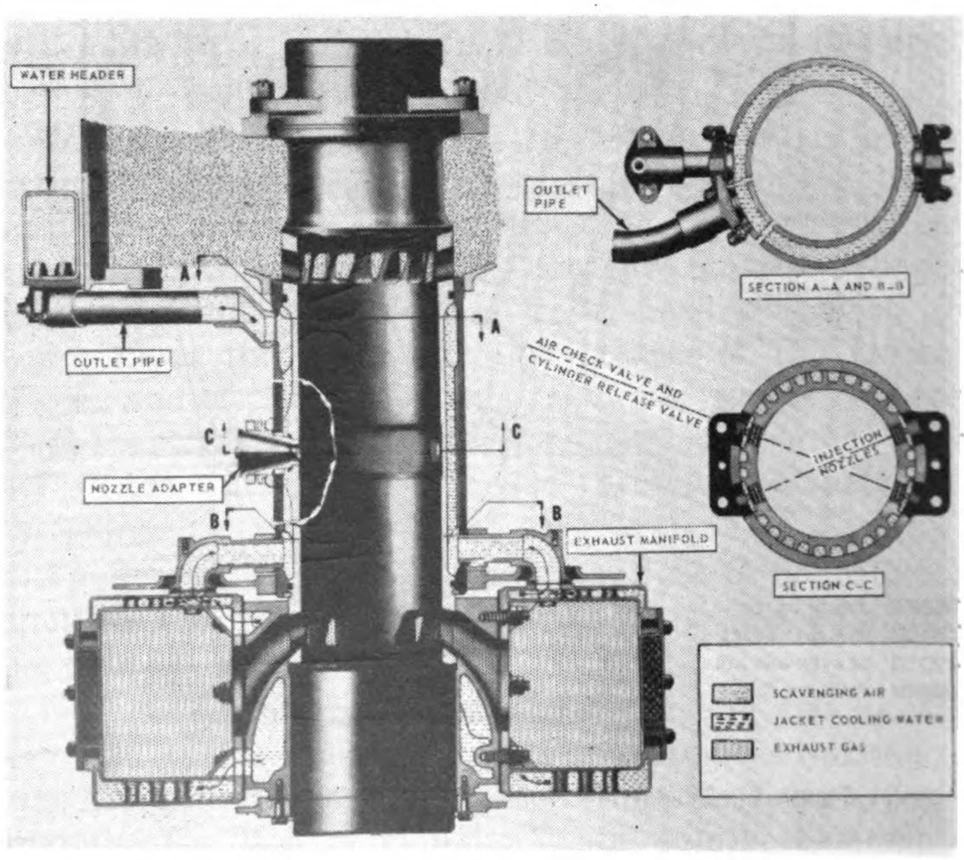


Figure 11–20.—Cooling-water passages in an FM opposed-piston engine.

pump usually enters the engine through the water jackets of the exhaust elbows and of the exhaust manifolds; in some cases, however, water enters the cylinder liner through a nozzle-adapter. In the usual arrangement, the water header or manifold in the FM 38D receives water from the cylinder-liner water passages (fig. 11–20). In other words, the water header of an FM 38D is the last passage in the engine through which water flows before it goes through the cooler and back to the pump; in the GM 16–278A and the GSB–8, the water header (manifold) is the first part to receive water from the pump.

Fresh Water (Expansion) Tanks

The fresh-water circuit of an engine cooling system includes a tank which is commonly referred to as the EXPANSION TANK. In some cases, the expansion tank is identified as the SURGE TANK or SUPPLY TANK.

PURPOSE.—The fresh-water tank provides a place where water may be added to the system when necessary and provides a space to accommodate variations in water volume which result from the expansion and contraction caused by heating and cooling of the water. The piping arrangement of a cooling system is such that excess water in the system is permitted to pass back to the tank as the water expands upon becoming warm; and that water from the tank is permitted to flow into the system when the water contracts as it cools, and when the water becomes low because of leakage in the system.

LOCATION.—Even though the exact locations of expansion tanks vary in different engines, the tank is always located at or near the highest point in the circuit. Examples of tank location are shown in figures 11–2, 11–3, and 11–14.

VENTING.—The manner in which venting is accomplished in the fresh-water circuit of a cooling system will vary, depending upon the engine. However, venting generally involves the expansion tank. In some cases, par-

ticularly in the systems of larger engines, a vent pipe from the high point of the circuit carries to the tank any steam or air bubbles which may form in the system. When steam comes in contact with the cooler water in the tank, the steam condenses back into water. This condensation keeps the system free from steam or air pockets. The expansion tank is vented to the atmosphere. A gage glass, located on the side of the tank, reveals the water level.

In many small engines, the fresh-water circuit has no vent and operates under a slight pressure (fig. 11–14). This arrangement confines the water vapor, thus preventing the loss of water. The only escape for water vapor from a circuit which operates under pressure is through a small overflow-pipe.

Sea Scoops and Strainers

All sea-water circuits include either scoops or a sea chest, located below the water line, to provide the sea water necessary to cool the water in the fresh-water circuit. A strainer is incorporated in the sea-water circuit to prevent the entrance of seaweed and other debris. In some cases, two strainers (inboard and outboard) are installed. The outboard strainer covers the sea-water inlet; the inboard strainer prevents small particles of foreign matter which passed through the outboard strainer from entering the circuit. Sea water strainers have removable strainer baskets, which can be withdrawn for cleaning.

An example of one type of scoop arrangement is shown in figure 11–2. Two scoops, inlet and outlet, are located in the bottom of the boat. These scoops may be opened or closed from controls located in the engineroom. When the boat is under way, its movement forces sea water into the inlet scoop, through the cooler, and out through the outlet scoop. When the boat is not under way and the engines are idling, the outlet scoop is closed and sea water is drawn in through the inlet scoop and cooler by the salt-water pump.

Valves

The quantity of coolant flowing to the various components of an engine cooling system is regulated by valves of various types. All valves used, however, fall into two general classifications: manually-operated valves and automatic valves.

Manually-operated valves include all valves, whether of the screw-down (gate, globe) or plug-cock type, that are adjusted by hand. Automatic valves include check valves, thermostatic valves, and pressure-regulating valves. The principles of operation of these valves, except those of the thermostatic type, are given in *Fireman,* NavPers 10520–A.

Many of the valves used in engine cooling systems are of the three-way proportioning type. Valves of this type are commonly used to regulate or proportion the quantity of sea water passing through coolers, silencers, and strainers. Such valves have one inlet, of fixed size; and two outlets, whose effective sizes can be varied simultaneously by either manual or thermostatic adjustment. Thus, by increasing the size of one outlet and reducing the size of the other outlet at the same time, water may be diverted from one outlet to the other.

Valves of the thermostatic type are commonly found in the cooling systems of modern engines. However, manually operated proportioning valves may be used to regulate the flow of coolant to wet-type silencers and auxiliaries. Also, some engine installations are equipped with manually operated valves for controlling engine coolant temperatures. Information on how valves are used to control engine temperature is included in chapter 13, Engine Operating Procedures. Information on valve maintenance is included in chapter 15.

SUMMARY

Most modern marine engine installations have closed cooling systems. Systems of this type generally have two separate circuits, wherein fresh water removes heat from the engine, and, in turn, is cooled by sea water in a cooler.

Open (single-circuit) systems provide cooling by pumping sea water directly into the engine passages. The open system is not as desirable as the closed cooling system because the open system permits greater scaling, and allows foreign matter and marine growth to accumulate in the engine passages, instead of in the more easily cleaned cooler.

Only clean, preferably treated, water should be used in a closed cooling system. Scale forms readily when contaminated water is used, and a small amount of scale, acting as insulation, causes overheating. Overheating in an engine must be avoided or the film of lubricating oil between bearing surfaces may be destroyed, clearances may be excessively reduced, and the structural strength of the metal may be reduced.

The sequence of the parts through which water flows in a closed cooling system is not the same in all engines. In general, however, the following is true in V-type and in-line engines. The coolant in the fresh-water circuit is circulated continuously by an attached pump. Water from the pump is forced into the water manifold(s), up through liner passages or block passages, and into the cylinder head(s). From the cylinder head, the water generally passes through exhaust cooling jackets and then through the fresh-water cooler. After the temperature of the fresh water is reduced in the cooler, the water may or may not, depending on the installation, pass through the lubricating-oil cooler. The water then returns to the suction side of the fresh-water pump to be recirculated. In opposed-piston engines, the path of the fresh water is different; it passes through the exhaust water jackets before it flows through the liner passages, and then through a water header before going to the cooler.

In the salt-water circuit of most closed cooling systems, we find that a salt-water pump draws water from the sea, through a sea chest or a scoop, strainer(s), and sea valves; and then discharges it through the fresh-water

cooler. From the fresh-water cooler, the sea water is discharged overboard. In some installations, sea water passes through the lubricating-oil cooler and the exhaust cooling passages before it is discharged overboard.

In addition to the attached fresh- and salt-water pumps, an electrically-driven detached pump is provided in most closed cooling systems. The detached pump is used in the event that either of the attached pumps fail. A detached pump is also used, in some installations, for cooling purposes after an engine has been secured.

QUIZ

1. List three reasons why the temperature of an engine must not be allowed to exceed a specified limit.
2. How may excessive heat in an engine affect lubrication?
3. How may too low an engine temperature affect the lubricating oil and the cylinders of an engine?
4. How may inadequate engine cooling cause a wrist pin to seize?
5. Trace the path which water follows in a typical open cooling system, by listing the various parts and passages in the proper order.
6. Does the water flow through the exhaust-silencer water jacket after passing through the engine in all open cooling systems?
7. In engines equipped with open cooling systems, what are two possible sources of the heat that is used to raise the temperature of engine intake water?
8. In a closed cooling system, how is salt-water cooling of the fresh water accomplished if there is no separate sea-water circuit?
9. Starting with the discharge side of the fresh-water pump, trace the path of water through the fresh-water circuit of a cooling system by listing the parts and passages in the proper order.
10. Trace the path of water through the sea-water circuit of a closed cooling system by listing the parts and passages in the proper order.
11. Why is an auxiliary, or detached, pump provided in the cooling systems of some engines?
12. Name three ways in which the fresh- and sea-water pumps of a cooling system may differ.
13. Name three types of pumps which are used in engine cooling systems.

14. Of the three types of pumps used in engine cooling systems, which is the most common?
15. Name three methods by which the pumps of a cooling system may be driven.
16. Name three fluids, essential to engine operation, the temperatures of which are maintained at proper operating levels by coolers.
17. Coolers, as used in the cooling systems of engines, may be of what three types?
18. Name the two principal parts of a shell-and-tube cooler.
19. Describe briefly the paths which the cooling and cooled liquids generally take through a shell-and-tube cooler.
20. In a shell-and-tube cooler, why is one of the tube sheets so arranged that it "floats" within the shell?
21. What is meant by the term counterflow, when it is used to describe a type of shell-and-tube cooler?
22. Is a strut-tube cooler larger or smaller than a shell-and-tube cooler which provides the same amount of heat transfer?
23. If a strut-tube cooler and a shell-and-tube cooler provide an equal amount of heat transfer, which will withstand a higher degree of scaling and larger foreign particles without clogging the cooling system?
24. Name three functions served by the "struts" in a strut-tube water cooler.
25. Of the three types of coolers used in engine cooling systems, which one is used only for the cooling of lubricating oil?
26. What is a "hull" cooler?
27. What devices are installed in the salt-water circuit of an engine cooling system to protect the circuit from corrosion caused by electrolysis?
28. Do the devices which are installed to protect the sea-water circuit from corrosion prevent galvanic action?
29. What terms are used to distinguish between the forms, or types, of zincs?
30. Which of the engine cooling passages which are common to in-line and V-type engines are not found in engines of the opposed-piston type?
31. Indicate how the paths of water through the GM 16–278A and FM 38D differ, by listing, in the order of flow, the parts and passages for each engine (start and end with the pump).
32. What is the purpose of the tank that is provided in the fresh-water circuit of an engine cooling system?

CHAPTER 12

DRIVE MECHANISMS

(Transmission of Engine Power)

The main components of an engine have been covered in the preceding chapters of this course. If the power developed by an engine is to be utilized to perform useful work, some means must be provided to transmit the power from the engine (driving unit) to such loads (driven units) as the propeller(s) of a ship or boat or the drive shafts of a generator, a compressor, or a pump. This chapter provides general information on how the force available at the crankshaft of an engine is transmitted to a point where it will perform useful work. The combination of devices used to transmit engine power to a driven unit is commonly called a drive mechanism.

FACTORS RELATED TO THE TRANSMISSION OF ENGINE POWER

The fundamental characteristics of an internal combustion engine make it necessary, in many cases, for the drive mechanism to change both the speed and the direction of shaft rotation in the driven mechanism. There are various methods by which required changes of speed and direction may be made during the transmission of power from the driving unit to the driven unit. In most of the installations with which you will be working, however, the job is accomplished by a drive mechanism consisting principally of gears and shafts. The manner in which a

drive mechanism transmits power will be easier to understand if you review chapters 1 through 9 of *Basic Machines*, NavPers 10624. Chapter 6 of *Basic Machines* will be especially helpful to you; it describes the basic types of gears and discusses the manner in which gears are used to change the direction of rotation and the speed of a shaft.

The process of transmitting engine power to a point where it can be used in performing useful work involves a number of factors. Two of these factors are torque and speed.

Torque

The force which tends to cause a rotational movement of an object is called torque, or "twist." The crankshaft of an engine supplies a twisting force to the gears and shafts which transmit power to the driven unit. Gears are used to increase or decrease torque. For example, an engine may not produce enough torque to turn the shaft of a driven machine if the connection between the driving and driven units is direct, or "solid." If the right combination of gears is installed between the engine and the driven unit, however, torque is increased and the twisting force is then sufficient to operate the driven unit.

Speed

Another factor related to torque and to the transmission of engine power is engine speed. If maximum efficiency is to be obtained, an engine must operate at a certain speed. In order to obtain efficient engine operation, it may be necessary, in some installations, for the engine to operate at a higher speed than that required for efficient operation of the driven unit. In other cases, the speed of the engine may have to be lower than the speed of the driven unit. Through a combination of gears, the speed of the driven unit can be increased or decreased so that both driving and driven units operate at their

most efficient speeds; that is, so that the proper speed ratio exists between the units.

The terms speed ratio and gear ratio are frequently used in descriptions of gear-type mechanisms. Both ratios are determined by dividing the number of teeth on the driven gear by the number of teeth on the driving gear. For example, assume that the crankshaft of a particular engine is fitted with a driving gear which is half as large as the meshing, driven gear. If the driving gear has 10 teeth and the driven gear has 20 teeth, the gear ratio is 2 to 1. Every revolution of the driving gear will cause the driven gear to revolve through only half a turn. Thus, if the engine is operating at 2000 rpm, the speed of the driven gear will be only 1000 rpm; the speed ratio is, then, 2 to 1. This arrangement doubles the torque on the shaft of the driven unit; the speed of the driven unit, however, is only half that of the engine.

On the other hand, if the driving gear had 20 teeth and the driven gear had 10 teeth, the speed ratio would be 1 to 2, and the speed of the driven gear would be doubled. The rule applies equally well when an odd number of teeth is involved. If the ratio of the teeth is 37/15, the speed ratio is slightly less than 2.47/1; in other words, the driving gear will turn through almost two and a half revolutions while the driven gear makes one revolution. The gear with the greater number of teeth, which will always revolve more slowly than the gear with the smaller number of teeth, will produce the greater torque. Gear trains which change speed always change torque; when speed increases, the torque decreases proportionally.

TYPES OF DRIVE MECHANISMS

It has been pointed out in the preceding section of this chapter that it may be necessary to change the torque and the speed of an engine to satisfy the torque and speed requirements of the driven mechanism. The term INDIRECT DRIVE, as used in this chapter, describes a drive mechanism

which changes speed and torque. Drives of this type are common to many marine engine installations.

In some cases, however, the speed and the torque of an engine need not be changed in order to drive a machine satisfactorily. In such cases, the drive mechanism which is used is a DIRECT DRIVE. Drives of this latter type are commonly used where the engine furnishes power for the operation of auxiliaries, such as generators and pumps.

Indirect Drives

The drive mechanisms of most engine-powered ships and of many boats are of the indirect type. With this drive, the power developed by the engine(s) is transmitted to the propeller(s) indirectly, through an intermediate mechanism which reduces the shaft speed. Speed reduction may be accomplished mechanically, by a combination of gears, or by electrical means.

MECHANICAL DRIVES.—The drives of this type which are discussed in this chapter include devices which reduce the shaft speed of the driven unit, provide a means for reversing the direction of shaft rotation in the driven unit, and permit quick-disconnect of the driving unit from the driven unit.

Propellers operate most efficiently in a relatively low rpm range; the most efficient designs of Diesel engines, however, operate in a relatively high rpm range. In order that both the engine and propeller may operate efficiently, the drive mechanism in many installations includes a device which permits a speed reduction from engine shaft to propeller shaft. The combination of gears which effects the speed reduction is called a REDUCTION GEAR. In most Diesel engine installations, the reduction ratio does not exceed 3 to 1; there are some units, however, which have reductions as high as 6 to 1.

The propelling equipment of a boat or a ship must be capable of providing backing-down power as well as

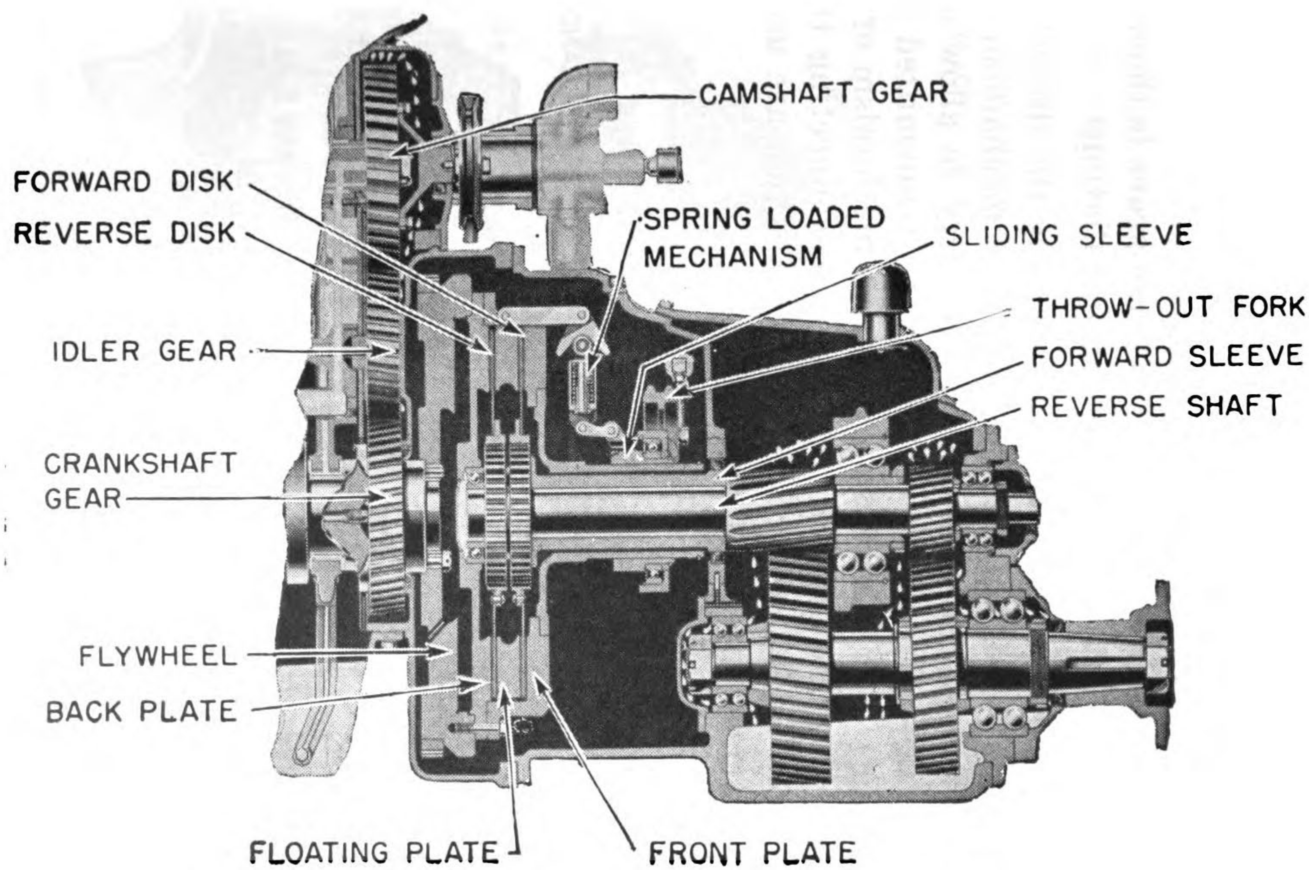


Figure 12—1.—Transmission with independent oil system.

forward motive power. There are a few ships and boats in which backing down is accomplished by reversing the pitch of the propeller; in most cases, however, backing down is accomplished by reversing the direction of rotation of the propeller shaft. In mechanical drives, reversing the direction of rotation of the propeller shaft may be accomplished in one of two ways: by reversing the direction of engine operation; or by the use of REVERSE GEARS. Of these two methods, the use of reverse gears is the one more commonly employed in modern installations.

More than reducing speed and reversing the direction of shaft rotation is required of the drive mechanism of a ship or a boat. It is frequently necessary to allow an engine to operate without power being transmitted to the propeller. For this reason, the drive mechanism of a ship or boat must include a means of disconnecting the engine from the propeller shaft. Devices which are used for this purpose are called CLUTCHES.

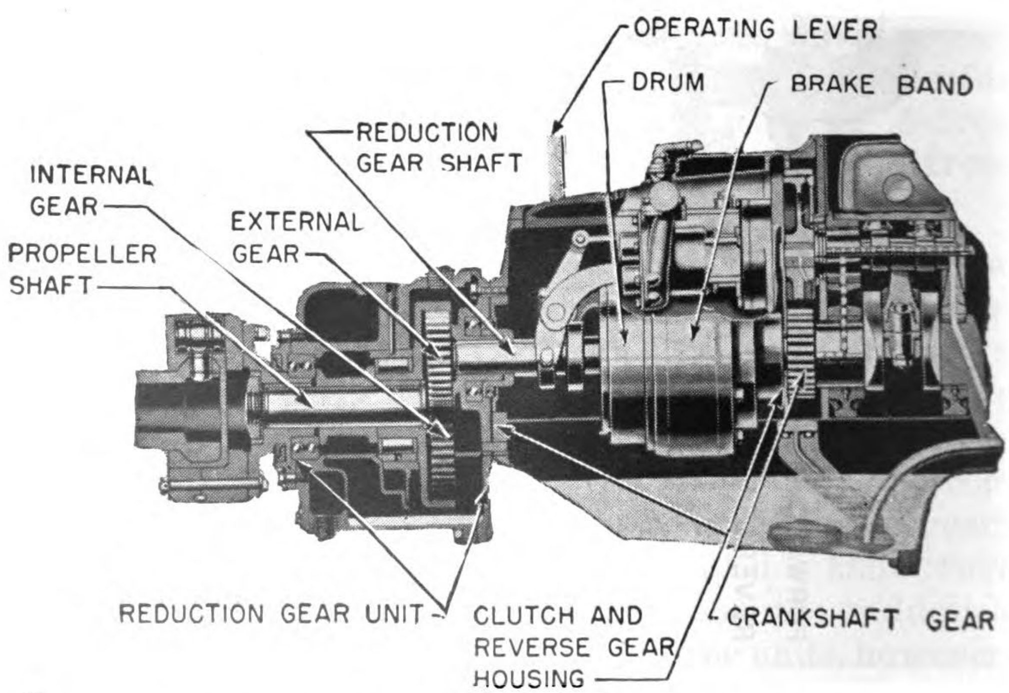


Figure 12–2.—Clutch and reverse-gear assembly with attached reduction-gear unit.

The arrangement of the components in an indirect drive varies, depending upon the type and size of the installation. In some small installations, the clutch, the reverse gear, and the reduction gear may be combined in a single unit; in other installations, the clutch and the reverse gear may be in one housing and the reduction gear in a separate housing attached to the reverse-gear housing. Drive mechanisms arranged in either manner are usually called transmissions. The arrangement of the components in two different types of transmissions are shown in figures 12–1 and 12–2.

In the transmission shown in figure 12–1, the housing is divided into two sections by the bearing carrier. The

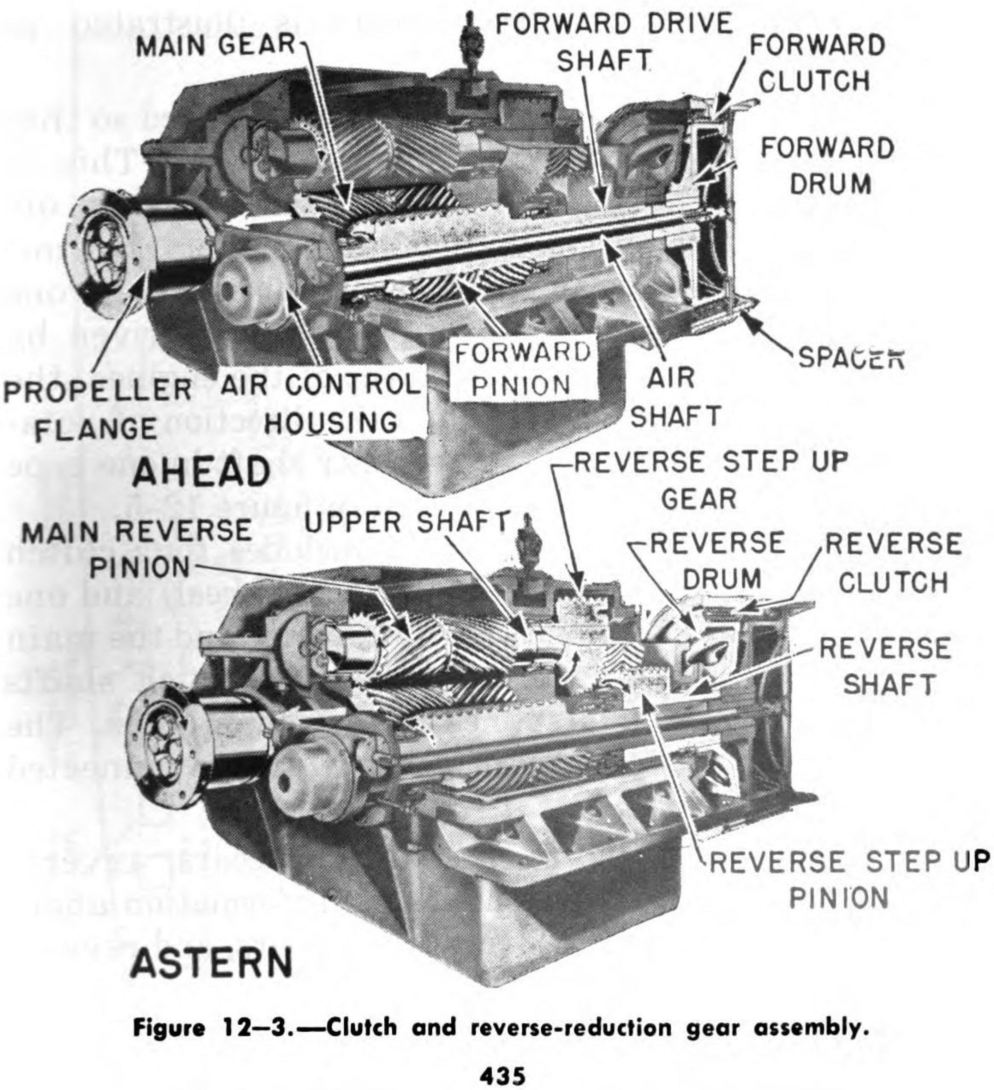


Figure 12–3.—Clutch and reverse-reduction gear assembly.

clutch assembly is in the forward section, and the gear assembly is in the after section of the housing. In the transmission shown in figure 12–2, note that the clutch assembly and the reverse-gear assembly are in one housing, while the reduction-gear unit is in a separate housing (attached to the clutch and the reverse-gear housing).

In large engine installations, the clutch and the reverse gear may be combined; or they may be separate units, located between the engine and a separate reduction gear; or the clutch may be separate and the reverse gear and the reduction gear may be combined. An assembly of the last type mentioned is shown in figure 12–3.

In most, geared-drive, multiple-propeller ships, the propulsion units are independent of each other. An example of this type of arrangement is illustrated in figure 12–4.

In some cases, the drive mechanism is arranged so that two or more engines drive a single propeller. This is accomplished by having the driving gear which is on, or connected to, the crankshaft of each engine transmit power to the driven gear on the propeller shaft. In one type of installation, each of two propellers is driven by four Diesel engines. The arrangement of the engines, the location of the reduction gear, and the direction of rotation of the crankshaft and the propeller shaft in one type of "quad" power unit are illustrated in figure 12–5.

The drive mechanism illustrated includes four clutch assemblies (one mounted to each engine flywheel) and one gear box. The box contains two drive pinions and the main drive gear. Each pinion is driven by the clutch shafts of two engines, through splines in the pinion hubs. The pinions drive the single main gear, which is connected to the propeller shaft.

There are many types of reduction gears, reverse gears, and clutches in use in the Navy. Information about the various types of clutches, reduction gears, and reverse gears; and the principles of operation of each of these types of mechanisms are given in *Fundamentals of Diesel*

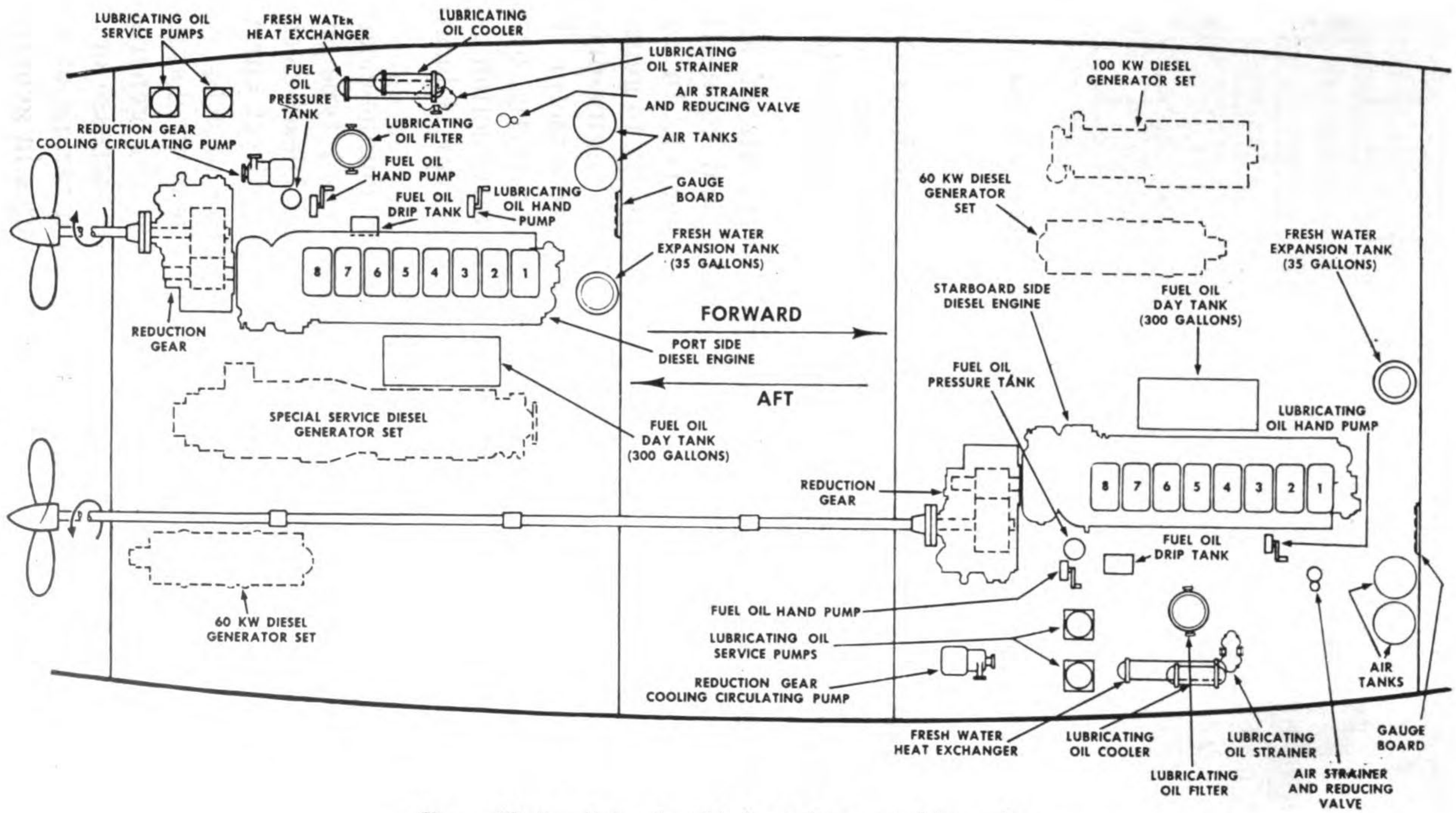


Figure 12-4.—Example of independent propulsion units.

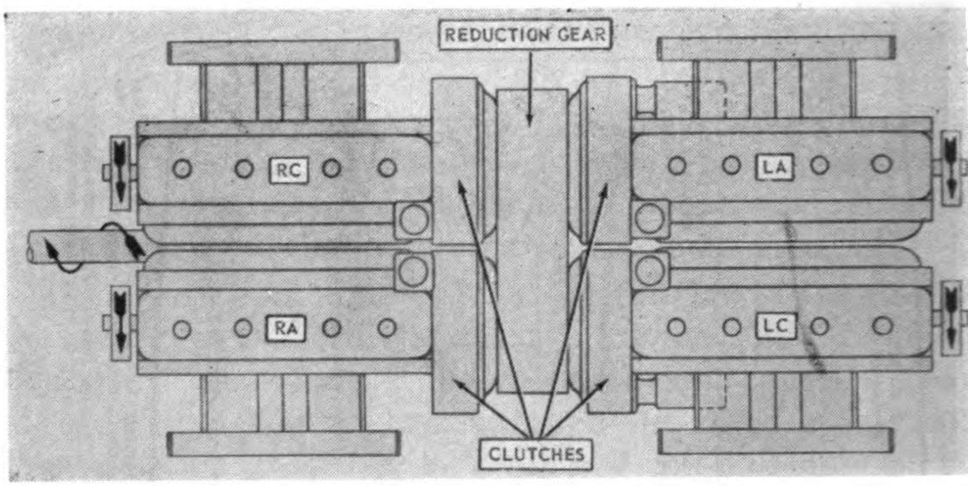


Figure 12–5.—Four engines ("quad" unit) arranged to drive one propeller (GM 6–71).

Engines, U. S. Navy, NavPers 16178–A. Additional information on specific units used for the transmission of engine power is provided in a more advanced training course for Enginemen.

ELECTRIC DRIVES.—In the propulsion plants of some Diesel-driven ships, there is no mechanical connection between the engine(s) and the propeller(s). In such cases, the Diesel engines are connected directly to generators. The electricity produced by such an engine-driven generator is transmitted, through cables, to a motor. The motor is connected to the propeller shaft directly, or indirectly, through a reduction gear. When a reduction gear is included in a Diesel-electric drive, the gear is located between the motor and the propeller.

The generator and the motor of an engine-electric drive may be of the alternating current (a-c) type or of the direct current (d-c) type; almost all Diesel-electric drives in the Navy, however, are of the direct current type. Since the speed of a d-c motor varies directly with the voltage furnished by the generator, the control system of an electric drive is so arranged that the generator voltage can be changed at any time. An increase or decrease in generator voltage is used as a means of controlling the speed of the propeller. Changes in generator

voltage may be brought about by electrical means, by changes in engine speed, and by a combination of these methods. The controls of an electric drive may be in a location remote from the engine, such as the pilot house.

In an electric drive, reversing the direction of rotation of the propeller is not accomplished by the use of a reverse gear. The electrical system is arranged so that the flow of current through the motor can be reversed. This reversal of current flow causes the motor to revolve in the opposite direction. Thus, the direction of rotation of the motor and of the propeller can be controlled by manipulating the electrical controls.

Direct Drives

In some marine engine installations, power from the engine is transmitted to the driven unit without a change in shaft speed; that is, by a direct drive. In a direct drive, the connection between the engine and the driven unit may consist of a "solid" coupling, a flexible coupling, or a combination of both. A clutch may or may not be included in a direct drive, depending upon the type of installation. In some cases, a reverse gear is included.

SOLID COUPLINGS.—Couplings of this type vary considerably in design. Some solid couplings consist of two flanges bolted solidly together. In other direct drives, the driven unit is attached directly to the engine crankshaft by a nut, as in the case of the P–500, centrifugal fire pump. In the case of this pump, the pump impeller is mounted directly on the engine crankshaft, which extends into the pump housing. (See fig. 12–6.)

Solid couplings offer a positive means of transmitting torque from the crankshaft of an engine; however, a solid connection does not allow for any misalignment nor does it absorb any of the torsional vibration transmitted from the engine crankshaft.

FLEXIBLE COUPLINGS.—Since solid couplings will not absorb vibration and will not permit any misalignment, most direct drives consist of a flange-type coupling which is used in connection with a flexible coupling. Connections

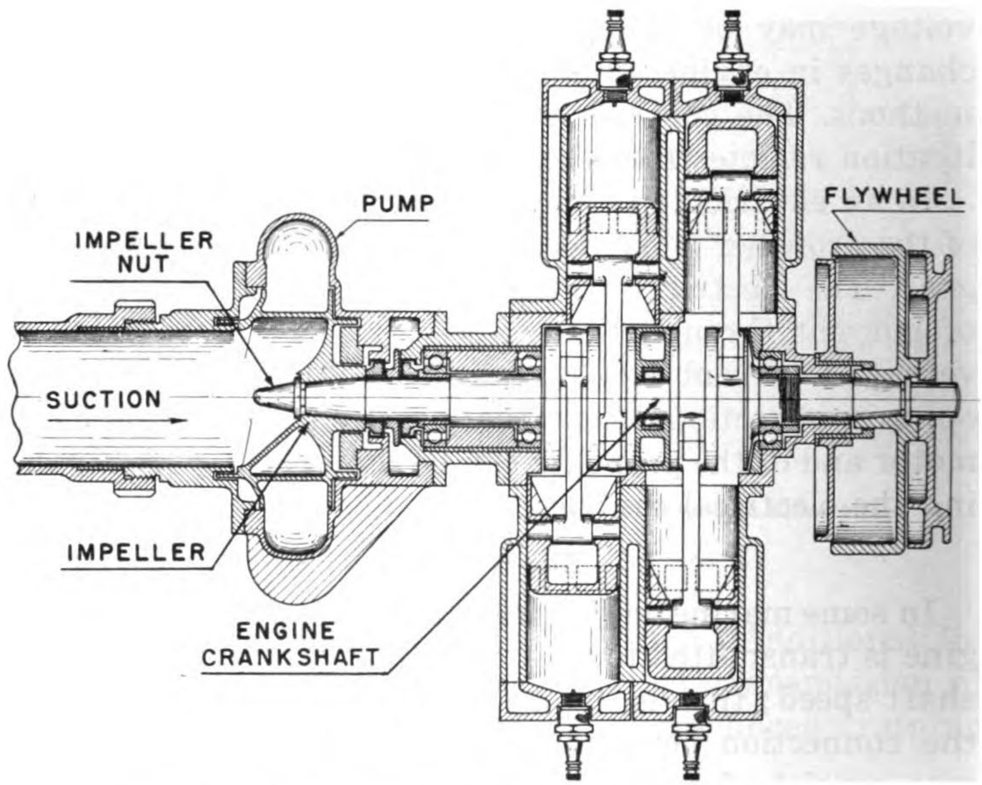


Figure 12–6.—Direct drive in an engine-driven pump.

of the flexible type are common to the drives of many auxiliaries, such as engine-generator sets. Flexible couplings are also used in indirect drives to connect the engine to the drive mechanism.

The two solid halves of a flexible coupling are joined by a flexible element. The flexible element is made of rubber, neoprene, or steel springs. Two views of one type of flexible coupling are shown in figure 12–7.

The coupling illustrated has radial spring packs as the flexible element. The power from the engine is transmitted from the inner ring, or spring holder, of the coupling, through a number of spring packs to the outer spring holder, or driven member. A large driving disk connects the outer spring holder to the flange on the driven shaft. The pilot on the end of the crankshaft fits into a bronze, bushed bearing on the outer driving disk to center the driven shaft. The ring gear of the jacking

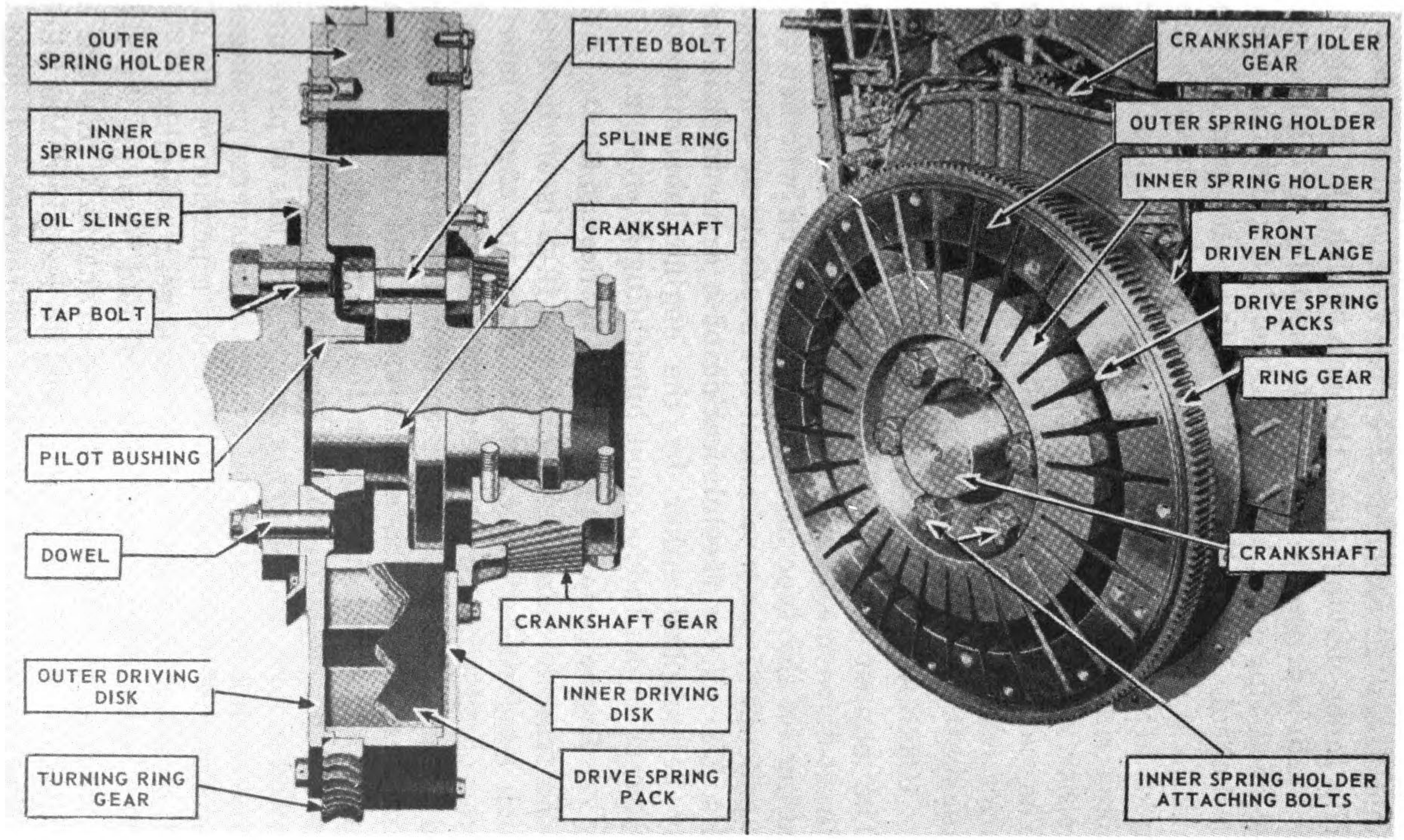


Figure 12–7.—Flexible coupling (GM 278A).

mechanism is pressed onto the rim of the outer spring holder.

The inner driving disk, through which the camshaft gear train is driven, is fastened to the outer spring holder. A splined ring gear is bolted to the inner driving disk. This helical, internal gear fits on the outer part of the crankshaft gear and forms an elastic drive, through the crankshaft gear which rides on the crankshaft. The splined ring gear is split and the two parts are bolted together with a spacer block at each split-joint.

The parts of the coupling shown in figure 12–7 are lubricated by oil flowing from the bearing bore of the crankshaft gear through the pilot bearing.

LUBRICATION OF INDIRECT-DRIVE MECHANISMS

The manner in which the principal components of an indirect-drive mechanism are lubricated will differ, depending on the type of mechanism and on whether the components of the mechanism are separate or combined units. The oil for the lubrication of a drive mechanism may be supplied either by the engine lubricating-oil system or by an independent lubricating-oil system.

Engine System as a Source of Lubricating Oil

The transmission shown in figure 12–2 is of the type which receives its lubricating oil from the engine lubricating-oil system. The housing prevents the escape of oil and the entrance of foreign matter. Oil from the after main bearing of the engine enters the transmission housing through a passage in the crankshaft. A restriction in the passage limits the amount of oil which is allowed to flow, and prevents an excessive loss of pressure in the engine lubricating-oil system. Transverse passages near the end of the crankshaft direct a portion of the oil to the pinion bearings in the reverse-gear assembly.

The reverse-gear shaft has a drilled passage. At the junction of this passage and the crankshaft passage a small amount of oil is permitted to leak into the pilot bearing. Near the forward end of the reverse-gear shaft, a transverse passage directs some of the oil to the thrust-

disk surface and into the gear-cage assembly. This supply of oil also lubricates the friction disks of the clutch.

The rotating motion of the parts in the gear-cage assembly causes some of the oil to escape from the interior of the assembly. This oil gathers on the exterior of the brake drum and lubricates the brake band. The remainder of the oil flows, through the passage in the reverse-gear shaft, to a transverse passage which directs oil to the throw-out assembly of the clutch. In installations where a reduction-gear unit is not attached, excess oil drains into the bottom of the transmission housing. The oil is then returned to the engine lubricating-oil system either by gravity or by a scavenging system, depending on the type of installation. In some cases where the reduction-gear unit is attached (fig. 12–2), oil is supplied to the reduction-gear unit through a passage in the reverse-gear shaft. The oil enters the reduction-gear housing and spills between the gears, flooding them with oil. The bearings in the reduction-gear unit are lubricated by splash.

In some transmissions, lubricating oil is supplied to the attached, reduction-gear unit by an external line from the engine system. The line to the reduction-gear housing connects to an adapter which provides for spraying the oil on the gears as they mesh. The bearings are lubricated by splash. Excess oil is returned to the engine lubricating-oil system either by gravity or by a scavenging pump.

Independent Lubricating-Oil Systems for Gear Assemblies

Not all drive mechanisms which consist of a combined clutch and reverse-reduction transmission are lubricated by oil from the engine lubricating-oil system. In some transmissions of the combined type, a lubrication system entirely separate from that of the engine is provided. The transmission shown in figure 12–1 has such an independent system. In transmissions with an independent

oil-system, the supply of oil is maintained in the sump of the reduction-gear housing. The gears dip into the oil and throw it about the interior of the gear housing. (See fig. 12–1.) When transmission lubrication is from an independent system, such items as pilot bearings and throw-out bearings are grease-lubricated through pressure fittings. In more recent transmissions, a pressure feed lubrication system is used.

Many large gear units of the type illustrated in figure 12–3 are also lubricated by systems which are independent of the engines. A schematic diagram of the lubrication system of a large, two-unit reverse-reduction gear installation is shown in figure 12–8.

Lubrication of the gears is provided by the main gear (fig. 12–3), the lower part of which is immersed in the oil in the reservoir. As the gear rotates, the teeth of the gear carry some oil which provides lubrication. Additional lubrication is provided by means of an auxiliary pump, which pumps oil from the reservoir, through a cooler and strainer, into the cover of the reverse-reduction gear unit. (See fig. 12–8.) The oil is then conveyed, by a series of troughs, to the various bearings and gears to provide lubrication. The oil drains back to the reservoir, in the base of the unit, for recirculation. In twin installations, a separate pump is used for each unit; a standby lubricating-oil system is interconnected for emergency use. (See fig. 12–8.)

As an EN3, you may be required to see that oil flow is maintained to the gears and bearings of transmissions and gear units, and to check for oil leaks. From the preceding descriptions of the various types of transmissions and gear units, it is obvious that the specific procedures to be followed depend upon the type of installation. It is essential, therefore, that you become thoroughly familiar with the lubrication instructions provided in the manufacturer's manual for your specific installation. The following general instructions should be observed, whenever they are applicable.

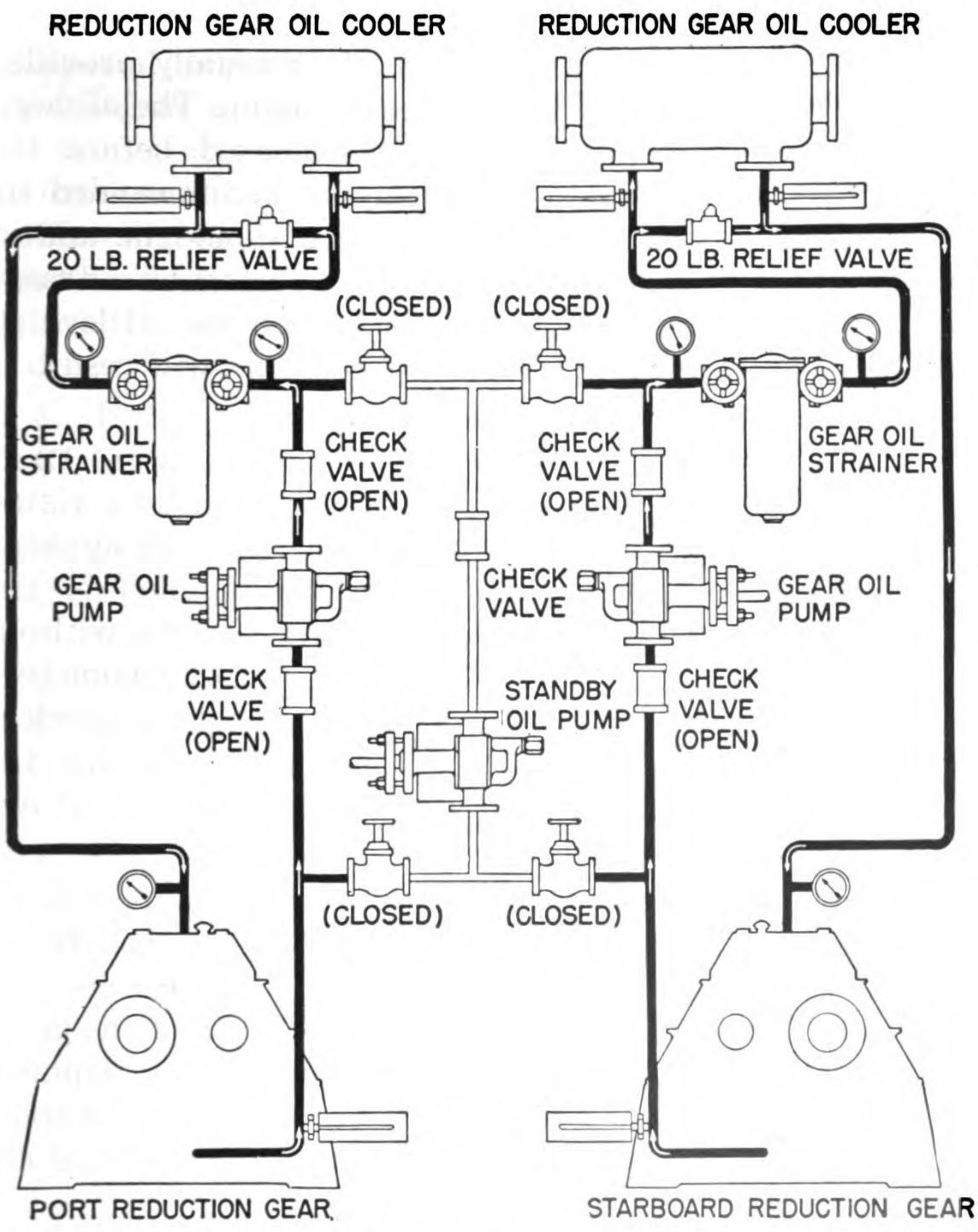


Figure 12—8.—Independent lubricating system for a large, reverse-reduction gear assembly.

In small transmission units where lubricating oil is supplied by the engine system, the instructions which apply to the operation and maintenance of the engine lubricating-oil system are equally applicable to the transmission. When transmissions have an independent lubricating-oil system, a gage (dip) stick is usually provided for checking the level of the oil in the sump. The oil level in independent systems should be checked before the engine is started; and subsequently, at recommended intervals. Oil of the recommended type should be added, whenever necessary. Do not fill the housing of a transmission above the prescribed level. When the oil level is too high, the gears will churn the oil; this will result in excessive temperatures and foaming.

In a large gear-unit of the type shown in figure 12–3, the delivery of oil to the unit can be checked by a visual oil-flow indicator. It is essential that oil at the designated working pressure and temperature be supplied to the gears while they are operating, whether with or without load. Therefore, the indicators, gages, and thermometers of a transmission or a gear assembly must be checked frequently during operation to determine whether the supply, the pressure, and the temperature of the oil are within recommended limits.

The oil level in a large reduction-gear unit can be checked with the gage rod, when the unit is at rest. When the unit is operating, the oil in the gear case must not rise above the recommended level on the teeth of the gear. The proper oil level in a reduction-gear unit depends upon the installation. The proper oil level for a particular, propulsion, reduction-gear unit is determined by the engineer officer.

In general, the oil in a gear case must not rise above the lower level of the teeth of the gear, unless an oil shield is fitted around the gear wheel for the purpose of carrying a higher level of oil. The oil level must be such that the gear will not churn and aerate the oil, since such action increases oil-temperature and foaming. These con-

ditions are indicated by an overflow of foaming oil through the escape vent (if provided) in the top of the gear case, and by oil leaks in the gear casing.

Precautions

Special precautions must be observed when a drive mechanism is being operated and maintained. The precautions which apply to a particular mechanism are given in the manufacturer's manual, which accompanies the unit or installation. Precautions are also posted near the installation. A few of the general precautions which apply to most drive mechanisms, whether they are small transmissions or large reverse-reduction gear units, are:

1. If the foaming of the oil in the gear case occurs, the unit must be slowed or stopped until the cause of trouble is located and eliminated.
2. If for any reason, the supply of lubricating oil to the gears fails, the gears must be stopped until the trouble is located and corrected.
3. Any unusual noise during gear operations must be investigated at once; the gears must be operated with caution until the cause of the noise is found and eliminated.
4. Never remove the inspection covers of a reduction gear while the unit is in operation.
5. Do not remove the inspection covers of a reduction gear unless you have permission to do so.
6. Naked lights and open flames must be kept away from open inspection ports or gear-case air vents at all times.
7. When inspection covers are replaced, be sure the covers are locked tight against the sealing rings. If oil leaks develop, the sealing rings should be replaced.

QUIZ

1. When a gear train is designed to increase the torque on the driven shaft, will the larger gear be the driving gear or the driven gear?
2. When a drive mechanism is designed so that the torque of the shaft of the driven unit is three times that of the shaft of the driving unit, what is the speed of the driven unit, compared to that of the driving unit?
3. What is the speed ratio of a gear train in which the driving gear has 24 teeth and the driven gear has 48 teeth?
4. Does the preceding example represent an increase or a decrease in the speed of the driven gear, compared to the speed of the driving gear?
5. Will a drive mechanism increase power?
6. State the three-fold purpose of an indirect-type, mechanical, drive mechanism.
7. Why are reduction gears necessary in the propulsion units of some vessels?
8. Give two methods by which the direction of rotation of the propeller may be reversed in mechanical-drive propulsion units.
9. Mechanical connections exist between all but which two major components of the propulsion plant in a Diesel-electric-driven vessel?
10. Most Diesel-electric drives in Navy installations operate on what type of current?
11. How is astern operation accomplished with an electric drive?
12. When a reduction gear is installed in a Diesel-electric drive, is the reduction gear located: (a) between the engine and the generator, (b) between the generator and the motor, or (c) between the motor and the propeller?
13. State two advantages that a flexible-type coupling has over a solid-type coupling.
14. From what two sources may oil for the lubrication of gear assemblies in an indirect-drive mechanism be supplied?
15. State two ways in which oil may be returned from a transmission to the engine lubricating-oil system.
16. What is indicated by an overflow of foaming oil from the vent of a reduction-gear case?

CHAPTER 13

ENGINE OPERATING PROCEDURES—GENERAL

The two principal types of internal combustion engines used by the Navy include a wide variety of makes, models, and power ratings. Diesel engines are generally used, except where special conditions favor the use of gasoline. Standardization of Diesel fuel oils, fuel economy, reliability during starting and in getting underway, and the lesser fire hazard associated with the Diesel engine have been the chief factors in favor of this engine's use. However, the low weight-power ratio of the gasoline engine has caused it to be widely used in boat applications where both speed and light weight are required of the power plant. In many applications, gasoline engines are used instead of Diesel engines because of the relatively small size of the gasoline engines. Since the internal combustion engines in Navy service differ widely, not only in type but also in size and design, detailed information on the operation of each type and model of engine is far beyond the scope of this course. The information given in this chapter is applicable, in general, to all internal-combustion engine installations (propulsion and auxiliary) aboard Navy vessels. Detailed information on engine operation is available in BuShips-approved manufacturers' instruction books and in operating manuals which apply to each specific engine installation.

OPERATING INSTRUCTIONS FOR DIESEL ENGINES

(General)

You will be required, under a variety of conditions, to start, operate, stop, and secure engines. Check lists, detailing the steps to be followed in operating an engine under various conditions, are available for each installation. The applicable check list should be followed for each condition of operation of an engine; the precautions posted at the engine or listed in the applicable operating instructions must be observed.

Starting Procedures

Diesel engines are started by either an air-starting system or an electric-starting system. The starting procedure is essentially the same for both types of systems, except as noted in the following procedures.

The steps to be followed when a diesel engine is being started will depend upon whether the engine is being started after a routine securing, or is being started after an overhaul or a long period of idleness. General information on the procedures to be used in both conditions is given in this section.

STARTING AFTER A ROUTINE SECURING.—The following procedure applies when the engine has been idle for 4 hours or more. (When an engine has been idle for a shorter period of time, the starting procedure can be shortened considerably, in accordance with the applicable check lists.)

1. Set all valves in the sea-water cooling system in the proper position for normal operation.
2. Start separate motor-driven sea-water pump, if one is provided.
3. Vent all coolers, using the vent cocks.
4. Check the fresh-water cooling system. To do this, set all valves in their normal operating positions; start the motor-driven pump, if one is provided; and vent the system.
5. Check the level in the expansion tank; add clean, fresh water, if necessary.

6. Start the motor-driven lubricating-oil pump, if the engine is provided with one.

7. Check the level of the oil in the sump; add oil, if necessary.

8. Open all cylinder test valves or indicator cocks.

9. Turn the engine over several times, using the hand jacking gear or the motor-driven jacking gear. During this operation, the motor-driven lubricating-oil pumps should be in operation (or the engine should be primed by the hand-operated lubricating-oil pump).

10. Disengage the jacking gear.

11. Prime the fuel lines in the manner described in the manufacturer's instructions.

12. Close all cylinder test valves or indicator cocks; set all valves and cocks in the running position.

13. Start the engine, following the manufacturer's instructions closely.

14. During the first few minutes of operation, careful attention must be paid to all gages. If the lubricating-oil pressure does not rise immediately to the specified pressure, the engine must be shut down and the cause of the trouble investigated and remedied.

15. The engine should be brought up to speed gradually and the load should be applied gradually. After the engine has reached normal operating speed, the governor should be set for the desired operating speed.

STARTING AFTER OVERHAUL OR LONG IDLE PERIOD.—A Diesel engine which has been overhauled or which has been idle for a long period of time may be started in the normal manner after the steps in the following procedure have been completed:

1. Check all pipe connections and see that all systems are correctly connected.

2. Fill the engine's fresh-water cooling system to the proper level with clean, fresh water. (Apply hydrostatic test to cooling system if facilities are available.)

3. Start the motor-driven circulating-water pumps, if such pumps are provided; and check the gage pressures. Examine all pipes and fittings for leaks, especially the cylinder-liner packing glands and the other fittings inside the crankcase. Verify the flow of coolant through all cooling spaces; thoroughly vent the system, using the vent cocks.

4. Check the lubricating-oil system. Clean the strainers. Fill the oil sump to the proper level. If possible, take a sample of lubricating oil and check it for dilution. Also take a sample of oil from the bottom of the sump and check it, to determine whether any water is present. Remove any such water by running all the oil through the purifier, if one is provided. Where a separate filtering-system is provided, the oil may be cleaned by circulating it through the filtering system. This should not be done, however, until the oil has been heated. Where the installation permits, the lubricating oil should be heated to a temperature of at least 100° F before the engine is started.

5. Start the motor-driven lubricating-oil pump; or the hand-operated lubricating oil pump, if one is provided. Check all gage pressures. Inspection plates and covers should be removed; a visual check should be made to assure that the lubricating oil is reaching all points of the system, i.e., all main and connecting-rod bearings, camshaft bearings, blower bearings, rocker arms, wrist pins, etc. If it is found that the lubricating oil is not reaching all these parts, it will be necessary to determine and to correct the cause of the trouble. Examine all pipes and fittings for leaks.

6. Fill all grease cups and lubricators.

7. Where hydraulic governors are provided, see that they are filled to the proper level with the specified grade of lubricating oil.

8. Insofar as possible, examine all moving parts of the engine to see that they are clear for running.

9. Carefully examine all valve gear. Test all intake valves, exhaust valves, and air-starting valves, for freedom of movement. If the valves do not move easily, lubricate them with a mixture of fuel oil and lubricating oil; if this does not result in freeing the valves, they must be disassembled and cleaned. Check all valve clearances and make any necessary adjustments.

10. Check the timing of all fuel injectors, using the methods described in the manufacturer's instructions.

11. Fill the fuel service tank. Take a sample of fuel from the bottom of the service tank; examine it for water and sediment. Remove any water and sediment found; and refill the service tank, as necessary.

12. Start the auxiliary fuel-pumps, if such pumps are provided, and check all gage pressures. Examine all pipes and fittings for leaks, especially the fittings and lines inside the crankcase. Thoroughly vent all air from the fuel system, using the vent cocks.

13. Clean all fuel-oil strainers. Replace the elements in all fuel-oil filters, if conditions warrant the replacement. Where centrifuges are provided, centrifuge all the fuel oil in the service tank.

14. Disconnect the air-starting line; blow out all lines. Reconnect the line and build up the pressure in the air-starting bottles to the specified pressure.

15. Open all scavenging-air header drains. Open all exhaust-manifold drains. The engine is now ready to be started in the normal manner.

STARTING IN COLD WEATHER.—Compared to gasoline engines, diesel engines are hard to start at subfreezing temperatures. Friction horsepower in a diesel engine is relatively high because of the greater number of main bearings and piston rings required to carry the higher cylinder pressures found in this type of engine. Therefore, cranking speeds tend to be lower than for a comparable gasoline engine. At low temperatures, the heat of com-

pression is no longer adequate for ignition of the fuel. This condition can be corrected by the use of jacket-water heaters, but more than ½ hour is required to preheat an engine which is at $-20°$ F. Special starting aids and lubricants have been developed which permit the starting of some diesel engines at temperatures as low as $-20°$ F within a 60-second period. The lowest temperature at which an engine can be started without such aids ranges from about 70° F (for a nominal compression ratio of 12.5:1) to about 20° F (for a nominal compression ratio of 18:1).

The majority of cold-weather starting aids fall into two classifications: (1) air-intake heaters and glow plugs, used to heat the intake air or a portion of the cylinder charge and thereby raise the temperature in the engine cylinders above the ignition temperature of the fuel; and (2) various devices which furnish an auxiliary low-ignition-temperature fuel during the starting period.

A commonly used type of air-intake heater consists of an electrically heated resistance-grid, which is supported in the engine air-intake manifold by insulating blocks. The grid obtains its electrical energy from the engine-starting battery. The grid is heated to a bright-yellow color before the engine is cranked; it continues to function throughout the cranking period and until the engine is running smoothly.

Electric air-intake heaters are not used on 2-stroke-cycle engines. The large volume of air consumed and the heat losses to the cold metal in the scavenge-air blower and the air box would materially reduce the efficiency of such a heater in a 2-stroke cycle engine.

A fuel-oil-burning air-intake heater, called a flame primer, is widely used on both 2-stroke-cycle and 4-stroke-cycle engines. One type of flame primer assembly and mounting is shown in figure 13–1.

With a flame primer, fuel is sprayed into the engine air-intake manifold by means of a hand-operated pump and is ignited by means of a spark coil and a spark plug.

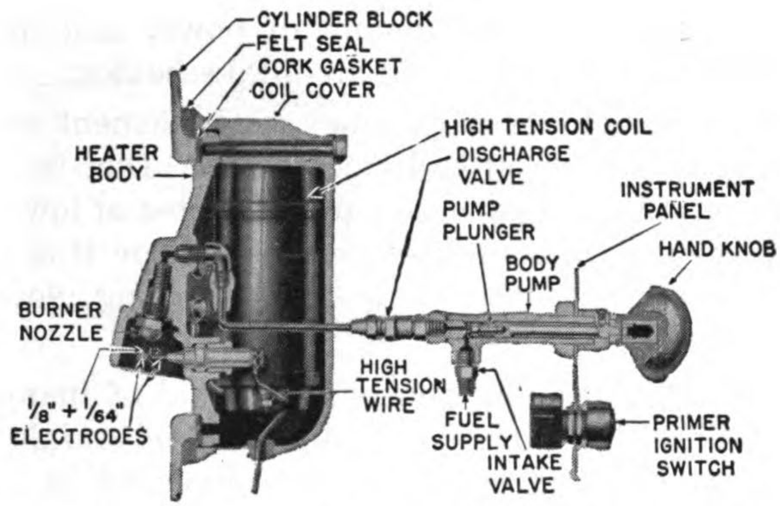


Figure 13–1.—Flame primer assembly (General Motors Corp.).

The flame primer consumes some of the oxygen in the intake air; it can, if improperly used, cause an oxygen deficiency in the engine cylinders. The flame primer has proved to be satisfactory for general use, however, when it is carefully maintained.

Another device which uses heat to improve starting is called a glow plug (fig. 13–2). A small coil of resistance wire, installed in the combustion chamber of each cylinder, is heated by current from the starting-battery. When the glow plugs are heated to a bright yellow, they supplement the regular ignition during starting. Glow plugs usually

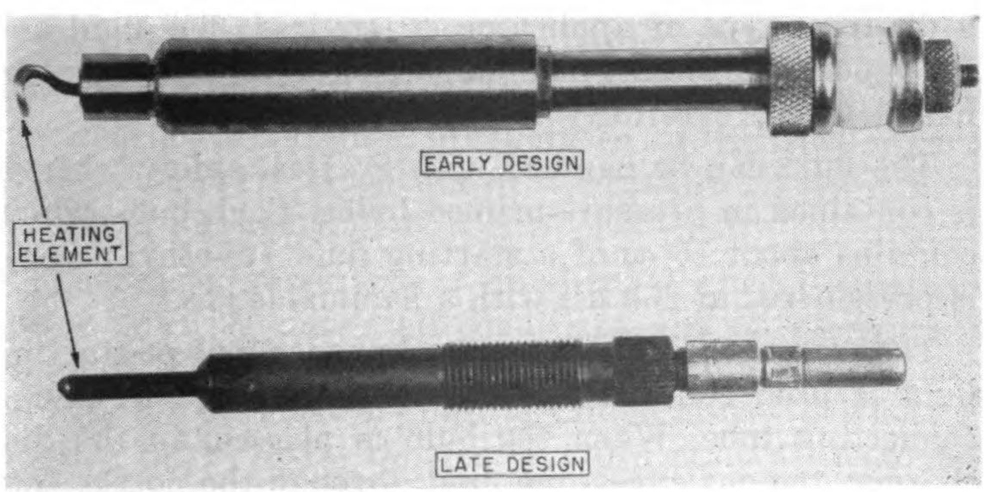


Figure 13–2.—Glow plugs.

require about the same amount of power and the same preheat-period as an electric air-intake heater.

In early designs of glow plugs, each element consisted of a single loop of large-diameter wire. Due to the low resistance of the wire, these plugs operated at low voltage and were usually connected in series. For this reason, failure of a single unit made the remaining glow plugs inoperative.

A modern glow plug consists of a coil of many turns of small-diameter wire, sheathed in a closed stainless-steel tube. Glow plugs of this type are connected in parallel. In the enclosed plugs, the resistance wire is not exposed to the corrosive conditions in the cylinder and they are not shorted out by carbon accumulations.

Ether is generally used as an auxiliary fuel for cold-weather starting. Because it ignites at a much lower temperature than fuel oil, ether is very helpful when sprayed into the engine air-intake manifold at the same time that the engine fuel-injection system is furnishing fuel to the engine cylinders in a normal manner. Most engines can be started at temperatures down to at least $-10°$ F when an ether-type starting fluid is used.

Ether-type starting fluid may be furnished in bulk; in sealed metal cans; or in metal, pressure-primer cartridges (sometimes called bulbs or capsules). In each case, a different type of applicator is required. The fluid and its vapors are highly flammable; it must, therefore, be handled very carefully.

The fluid can be handled with greatest safety when it is contained in pressure-primed bulbs. Each bulb, which contains about 10 cc of a starting fluid (di-ethyl ether), is pressurized at 250 psi with a flammable gas.

The system in which a pressure-primer bulb of starting fluid is used consists of a discharger, a nozzle, and a connecting tube. When the bulb is pierced, in the discharger, the gas expels the fluid, through the nozzle, into the air intake. Each bulb contains liquid for one start; the

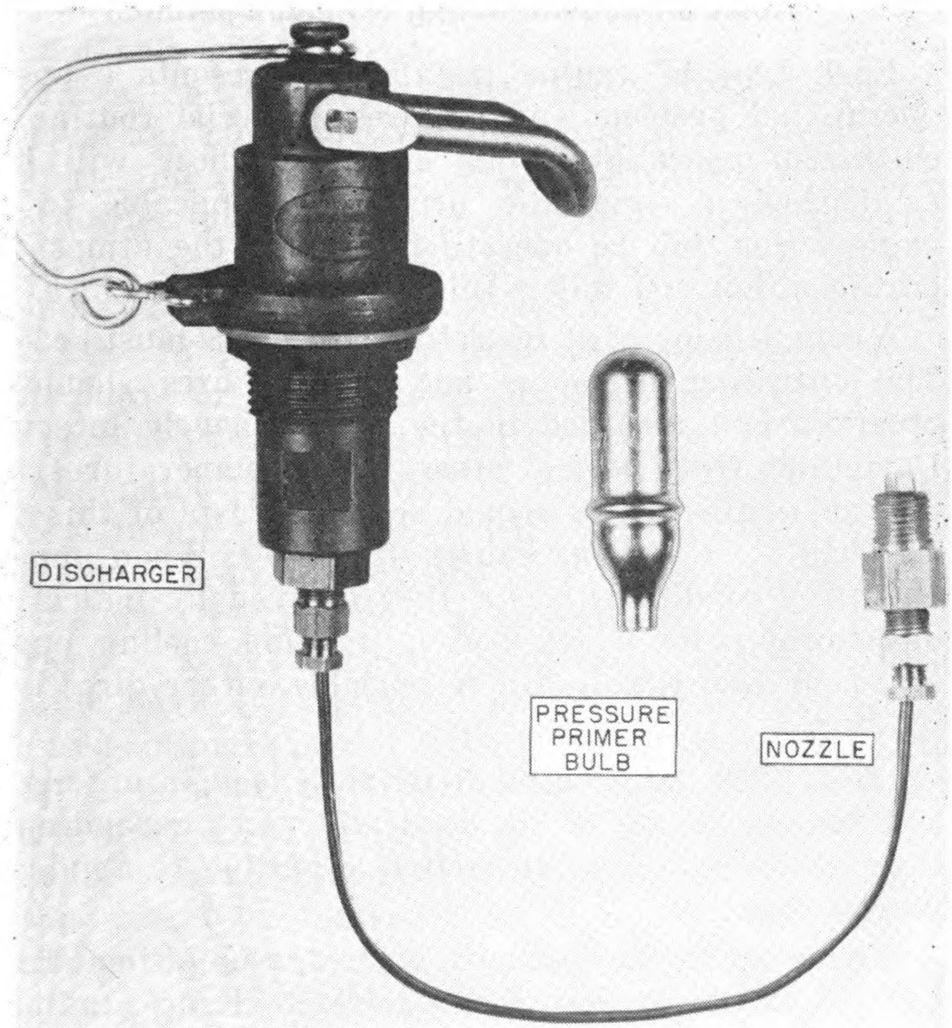


Figure 13–3.—Pressure-primer starting-fluid system.

bulb is discarded after use. Charged bulbs may be kept in the charger at all times, in readiness for use when needed. The principal components of a pressure-primer system are shown in figure 13–3.

There is no single type of starting aid which is outstandingly effective under all conditions and on all types of engines. However, ether-type starting fluid can be used effectively on most engines at temperatures down to at least —10° F. Below this temperature, ether seems to lack sufficient volatility to be of value in starting certain types of engines.

Notes on Routine During Normal Operation

Each type of engine installation presents a special operational problem and requires a special routine for successful operation. Your engineer officer will have established a systematic procedure applicable to the engines you will be operating. It is of the utmost importance that you follow this established procedure.

A complete log of all operating conditions must be kept. The operating pressures and temperatures should be observed and recorded in the log, at hourly intervals. Deviations from normal pressures or temperatures, and unusual engine noises should be noted. Data of this type are helpful in locating causes of trouble. When unusual operating conditions occur, they are usually indications of conditions for which load, lubrication, cooling, engine speed, or fuel supply are responsible, either directly or indirectly.

LOAD.—The manner of applying a load to an engine, and the regulation of the load will vary, depending on the installation. Load an engine according to applicable instructions.

Whenever a cold engine is started, ample time should be allowed so that the load can be built up gradually. Whenever the situation permits, the engine manufacturer's instructions regarding the application of load should be followed. Gradual application of the load is necessary to prevent damage to the equipment from such conditions as uneven rates of expansion and inadequate lubrication at low temperatures.

An engine should not be operated for any length of time with less than one-third normal load. Combustion at low load is incomplete; under these conditions, partially-burned fuel oil and lubricating oil may cause heavy carbon deposits, which will foul the valve stems, the piston rings, and the exhaust system.

The operation of a diesel engine at 30 percent power or less for long periods of time will lead to a number of

troubles. In addition to the formation of carbon on the intake and exhaust ports, on the combustion-chamber surfaces, on the piston head, and in the piston-ring grooves and lands, low-load operation may be responsible for sticking and burning of exhaust valves; dilution of the lubricating oil; scuffing of cylinder liners; increased fuel consumption; and excessive smoke when the load is increased. If operation requirements necessitate engine operation for periods in excess of thirty minutes at 30 percent power or less, the load should be increased to above 50 percent power at the first opportunity.

An engine should never be operated at an overload, except in an emergency. When conditions indicate that the engine is overloaded, the load should be reduced immediately. Overload may be indicated by excessive temperatures, smoky exhaust, or excessive firing-pressures.

LUBRICATION.—The importance of lubrication has been pointed out in chapters 9 and 10. During engine operation, keep in mind that you should watch mechanical oilers, when provided, to see that they are feeding properly and that they are not becoming air-bound. The oil level in the sump should be checked frequently; oil should be replenished, as necessary. All make-up oil should be purified, if feasible. Lubricating-oil purifiers, when provided, should be kept operating whenever the engines are in use; they should be operated periodically, during idle periods. The cleaning handle on all metal-edge type lubricating-oil strainers should be rotated through at least two complete revolutions during each watch. The pressure drop across the filters and strainers should be checked frequently. The viscosity of the lubricating oil should be checked at least once each day to determine the percent of fuel dilution.

PRESSURES AND TEMPERATURES.—All pressures and temperatures must be maintained within the normal operating ranges. All instruments must be checked frequently. The manufacturer's instructions give detailed information concerning the proper operating pressures and tempera-

tures. When this information is not available, the temperature of the lubricating oil as it leaves the engines should be maintained between 140° F and 180° F; and the temperature of fresh water should be not less than 140° or more than 170° F when the water leaves the engine. The temperatures in the salt-water cooling system should not be allowed to go above 130° F; higher temperatures will cause deposits of salt and other solids in the coolers and piping, and will aggravate corrosion. In order to ensure efficient operation in engines which are cooled by salt water, the temperature of the salt-water coolant should never be allowed to drop below 100° F at the engine discharge.

The temperatures in the cooling system must be regulated to meet the existing operating conditions. One of the principal factors affecting the proper cooling of an engine is the rate of flow of water through the cooling system. The more rapid the flow, the less danger there is of scale deposits and hot spots, since the high water-velocity has a scouring effect on the metal surfaces of the cooling passages; this effect causes the heat to be carried away more quickly. As the velocity of the circulating water is reduced, the discharge temperature of the cooling water becomes higher and more heat is carried away by each gallon of cooling water circulated. As the rate of circulation is increased, each gallon of cooling water carries away less heat and the discharge temperature of the cooling water drops; a relatively cool-running engine results.

The temperature of engine cooling water may be controlled by two methods. In one method, the water temperature is controlled by regulating the amount of water discharged, by the pump, into the engine. The other method of temperature control involves regulating the amount of water which passes through the fresh-water cooler. The first method may be accomplished by means of a manually-operated throttling valve; the latter method is

generally accomplished, automatically, by means of a thermostatically-operated bypass valve.

In cases where the MANUALLY-OPERATED THROTTLING VALVE is located in the pump discharge, the valve may be used to cause the water to pass through the engine slowly and be discharged at a high temperature; or to pass through the engine rapidly and be discharged at a low temperature. If the pump is driven by an electric motor, these same effects on the velocity and the discharge temperature of the cooling water can be obtained by increasing and decreasing the speed of the pump. In some cases, throttling-valves are used in the sea-water circuit to regulate the amount of water passing through the sea-water side of the fresh-water cooler.

An example of temperature control by means of a throttling valve in the sea-water circuit is shown in figure 11–2, lower illustration. In some installations of the system shown, engine temperature, in both the open and closed circuits, is controlled by opening or closing the throttling valve in the inlet scoop. In other installations of the system shown, temperature is controlled, automatically, by a thermostatically-operated bypass valve (upper illustration, fig. 11–2). In cases where throttling valves are incorporated in the sea-water circuit and a thermostatically-operated valve is included in the fresh-water circuit, the throttling valves are used only to provide a constant flow of sea water or to close the circuit completely. Temperature is controlled, in such cases, by the action of the thermostatically-operated valve in the fresh-water circuit. The throttling valve in the salt-water circuit should be adjusted to maintain the minimum flow of salt water consistent with maintaining proper temperatures in the fresh-water circuit and the lubricating oil system.

In modern, marine engine installations, automatic temperature control by means of THERMOSTATICALLY-OPERATED BYPASS VALVES is more common than control by means of throttling valves in the pump discharge or in

the sea-water circuit. The thermostatic valves used in the cooling systems of engines are of two types: the conventional type (an example of this type is shown in the upper illustration of fig. 11–2); and the three-way proportioning type. Valves of the latter type are commonly called automatic temperature-regulators. Conventional thermostatic valves are generally used in small engines; the temperature regulators are commonly used in medium and large engines.

The element is similar in both types of thermostatic valves. The element is so designed that it will expand or contract, depending upon the temperature to which it is exposed. The element of a thermostatic valve may be filled with a gas or a liquid, or it may be of the bi-metal type. In most marine engines, the elements of thermostatic valves are either gas-filled or liquid-filled. The elements of conventional thermostatic valves generally contain a gas; the elements of automatic regulators usually contain a volatile liquid, such as ether or alcohol. Elements, constructed in the form of a sealed bellows, may be made of copper, brass, or Monel metal. These metals are used because they are corrosion-resistant and because they will withstand a considerable amount of flexing without fatiguing. The element is attached to a valve, which opens and closes as the bellows expands and contracts under the influences of variations in the temperature of the coolant; thus, the amount of water flowing through the line is automatically regulated.

Conventional thermostatic valves may be built into the engine; or they may be located outside of the engine, within the fresh-water circuit, as illustrated in the upper illustration of figure 11–2. The manner in which a conventional thermostatic valve operates is illustrated in figure 13–4.

As long as the engine and the water are cool, the thermostatic valve remains closed; the water from the engine then flows around the bellows, down through the holes in the valve, and out through the bypass outlet to

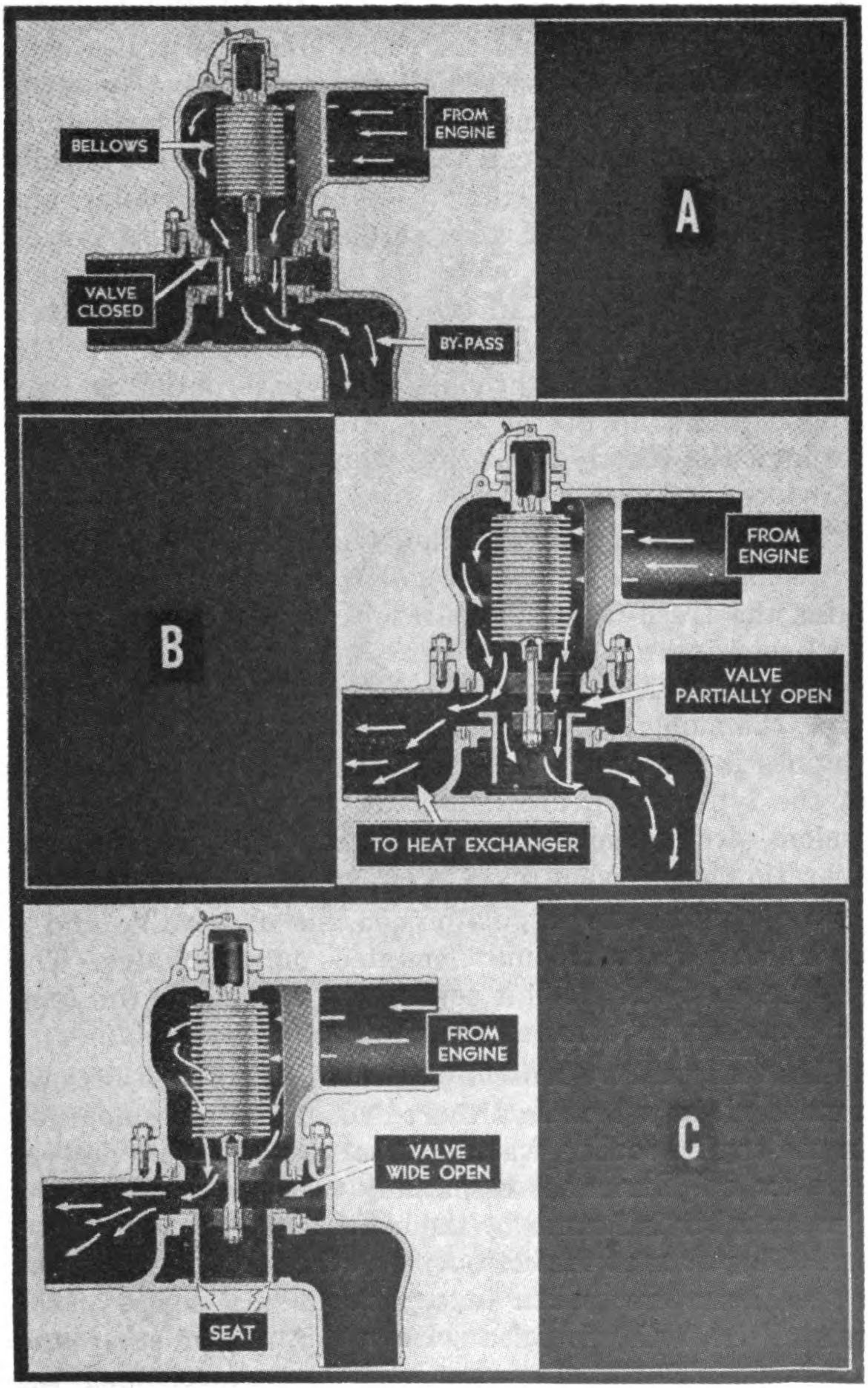


Figure 13–4.—Operation of a conventional thermostatic valve.

the fresh-water pump. (See A, fig. 13–4.) Fresh water is thus bypassed around the cooler until the water gets warm enough to cause the thermostatic valve to open. As the water gets warmer, the increase in temperature causes the element to expand; the valve is then partially opened, a part of the water goes through the cooler, and the rest of the water goes through the bypass outlet. (B, fig. 13–4.) Finally, when the valve is wide open, as a result of the increase in the temperature of the water, the valve seats on the base of the thermostat housing. The flow of fresh water through the bypass outlet is then stopped; and all of the water from the engine passes through the cooler, where the temperature of the water is reduced. (C, fig. 13–4.)

In many engines, fresh-water temperature is regulated by means of an automatic regulating valve which maintains the fresh-water temperature at any desired value by bypassing a portion of the water around the fresh-water cooler. An automatic temperature-regulator of the type commonly used in the cooling systems of marine engines is shown in figure 13–5. Even though regulators of the type shown are automatic or self-operated, provisions are included in most installations for manual operation in the event that the automatic feature fails.

The temperature regulator consists of a valve and a thermostatic control-unit mounted on the valve. The thermostatic control-unit consists of two parts, the temperature-control element and the control assembly.

The temperature-control element consists of a bellows connected, by a flexible armored tube, to a bulb mounted in the engine cooling-water discharge line. The temperature-control element is essentially two, sealed chambers. One chamber is formed by the bellows and cap, which are sealed together at the bottom; the other chamber is in the bulb. The entire system (except for a small space at the top of the bulb) is filled with a mixture of ether and alcohol, which vaporizes at a low temperature. When the bulb is heated, the liquid vaporizes and the pressure

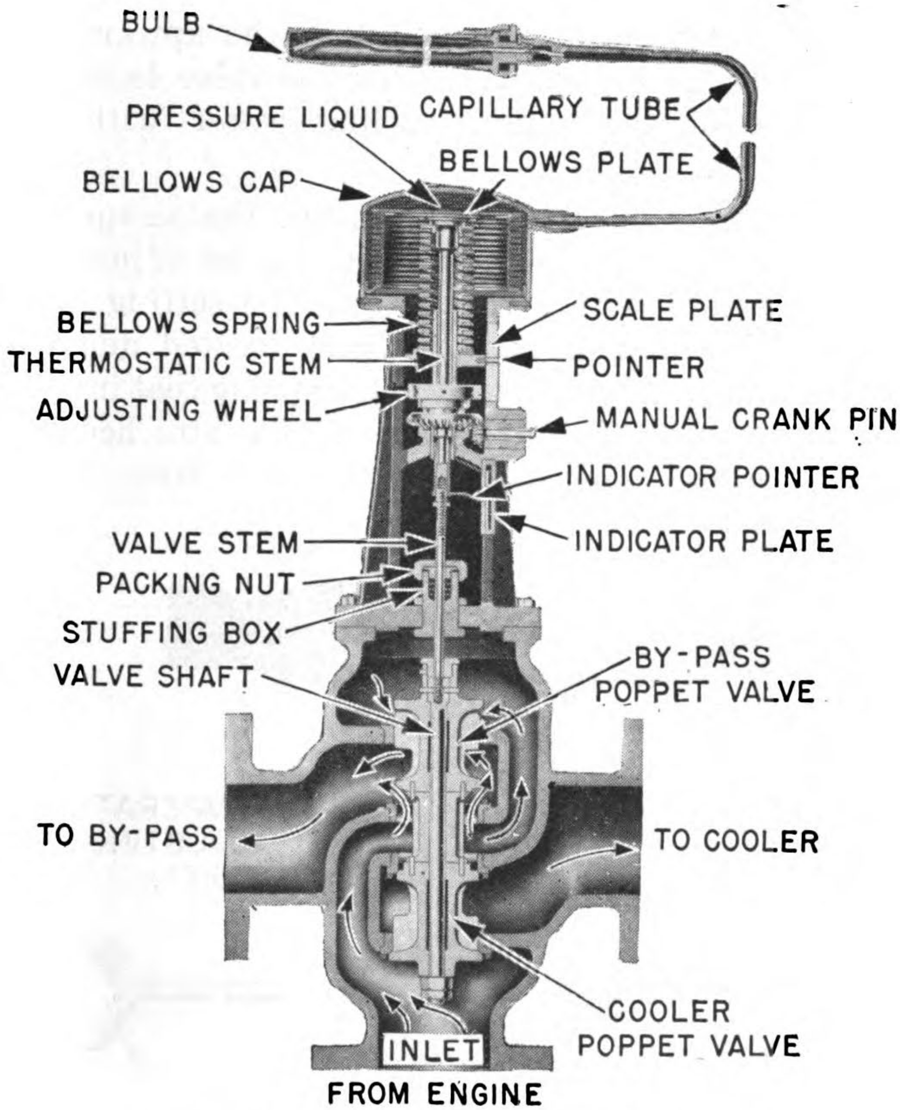


Figure 13–5.—Automatic temperature-regulator.

within the bulb increases. This forces the liquid out of the bulb and through the tube; the bellows is moved down and operates the valve.

The control assembly consists of a spring-loaded mechanical linkage which connects the temperature-control element to the valve stem. The coil spring in the control assembly provides the force necessary to balance the force of the vapor pressure in the temperature-control element.

Thus, the downward force of the temperature-control

element is balanced, at any point, by the upward force of the spring. This permits setting the valve to hold the temperature of the engine cooling water within the allowed limits.

The regulator operates only within the temperature range marked on the nameplate; it may be adjusted for any temperature within this range. The setting is controlled by the range-adjusting wheel, located under the spring seat. A pointer attached to the spring seat indicates the temperature setting on a scale which is attached to the regulator frame. The scale is graduated from 0 to 9,

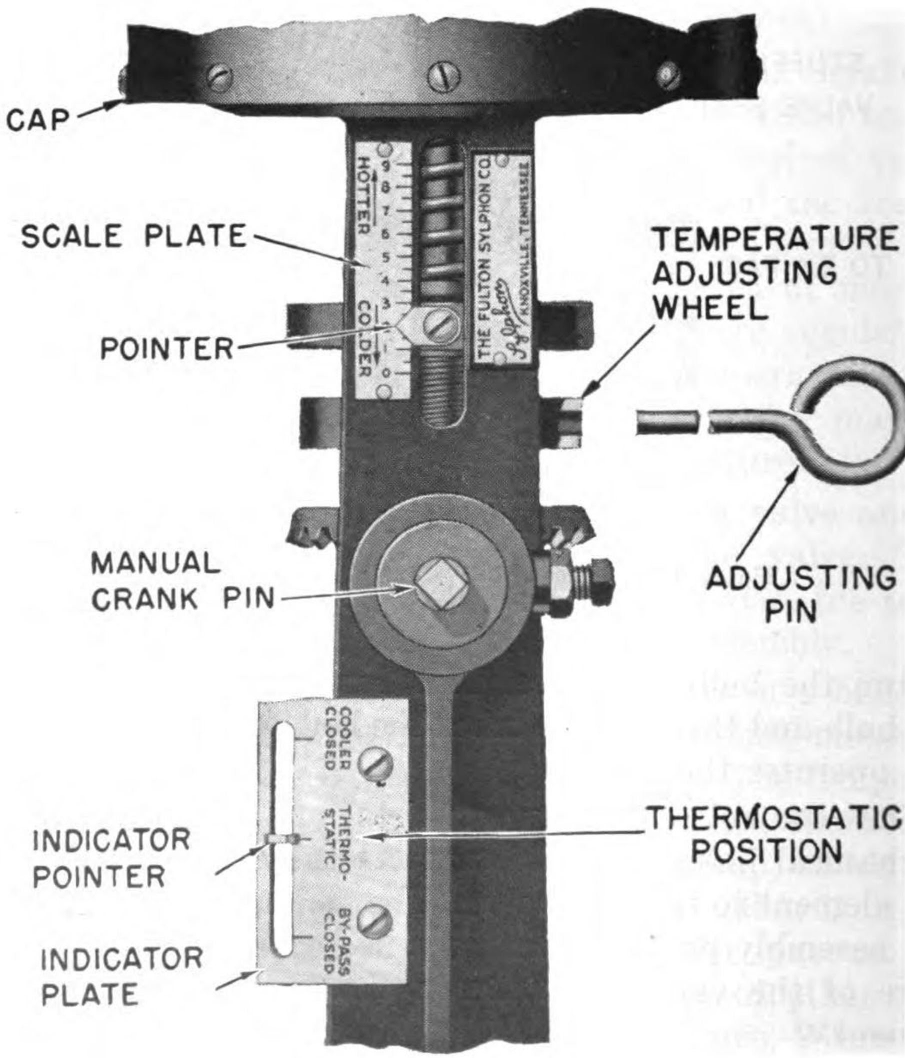


Figure 13–6.—Scale and indicator plates of temperature regulator.

representing the total operating range of the regulator. (See fig. 13–6.)

The location of a temperature regulator in one type of installation is shown in figure 11–15. Note that, in this case, the regulator is located in the sea-water circuit. In most engines, the regulator is located in the fresh-water circuit.

When located in the sea-water circuit, the regulator controls the amount of sea water flowing through the coolers. When the temperature of the fresh water becomes greater than the temperature for which the regulator is set, the regulator actuates a valve so as to increase the flow of sea-water through the coolers. When the fresh-water temperature is below the temperature for which the regulator is set, the regulator actuates a valve so as to decrease the flow of sea water through the coolers.

In installations where the regulator is in the fresh-water circuit, water is directed to the cooler when the temperature of the water is above the maximum setting of the regulator. After passing through the cooler, where the temperature of the water is decreased, the water returns to the suction side of the fresh-water pump, to be recirculated. When the temperature of the water is below the maximum setting of the regulator, the water bypasses the cooler and flows directly to the suction side of the pump. Bypassing the cooler permits the water to be recirculated through the engine; in this way, the temperature of the water is raised to the proper operating level.

Regardless of whether the regulator is in the fresh- or sea-water circuit, the bulb which causes the regulator to operate is located in the fresh-water discharge line of the engine.

Temperature regulators are used not only to control the temperature of the fresh water but also to control, indirectly, the temperature of the oil discharged from the lubricating-oil cooler. This control of lubricating-oil temperature is possible because the water (fresh water, in some cases; salt water, in others) that is passed through

the regulator and the fresh-water cooler is the cooling agent in the lubricating-oil cooler. In some cases, where the lubricating oil is cooled by sea water, two temperature regulators are installed in the sea-water circuit. The temperature-regulator bulb of the regulator which controls the temperature of the fresh water is installed in the fresh-water circuit; the bulb of the regulator that controls lubricating-oil temperature is installed in the lubricating-oil system.

Frequent checks of the cooling system should be made to detect any leaks. Coolers and heat exchangers should be vented at least once each watch. The level of the fresh water in the expansion tank should be checked frequently; fresh water should be added, as necessary. In case the level gets very low in the fresh-water system, cold water should never be added until the engine has cooled.

CRITICAL SPEEDS.—Do not operate an engine at or near any destructive critical speed; the vibrations resulting from operation at such speeds will cause serious damage.

All moving members of machinery have critical speeds. The term applies to certain ranges of speed, during which excessive vibration in the engine is created. Every part of the engine has a NATURAL PERIOD OF VIBRATION, or FREQUENCY. When impulses set up a vibration which coincides with the natural frequency of the body, each impulse adds to the magnitude of the previous vibration; finally, the vibration becomes great enough to damage the engine structure.

Vibration may be set up by lineal impulses from reciprocating parts or by torsional impulses from rotating members. The crankshaft is the member which causes torsional vibrations. The pressure impulse on the piston puts a twist in the crankshaft; when the pressure on the piston is somewhat relieved, the shaft untwists. If pressure impulses which are timed to the natural period of the shaft are permitted to continue, the vibration amplitude will become so great that the shaft may be fractured. If the speed of such an engine is changed, however, the

pressure impulses will no longer coincide with the natural period of the shaft; the vibration will then cease.

Since each engine has a natural period of vibration, which cannot be changed by the operator, the only control available to the operator is to avoid operating the engine at critical speeds. If critical speeds exist below the normal speed of the engine, the critical ranges must be passed through as quickly as possible when engine speed is being changed. Detailed information concerning critical-speed ranges are issued with each installation. Tachometers must be marked to show any critical speed ranges; this will make it easier to keep the engine out of the critical ranges. Tachometers sometimes get out of adjustment; they must, therefore, be frequently checked with mechanical counters.

FUEL.—An adequate supply of proper fuel must be maintained. The fuel system should be frequently checked for leaks. All fuel-oil strainers should be cleaned, at periodic intervals. Fuel-oil-filter elements should also be replaced, whenever necessary. (See chapters 7 and 14.) When Diesel fuel oil purifiers are provided, all fuel should be purified before it is transferred to the service tank. The service tank should be frequently checked for water and other settled impurities by sampling through the drain valve at the bottom of the tank. Water and impurities should be drained off.

Stopping and Securing Procedures

Diesel engines are stopped by shutting off the fuel supply. This is accomplished by placing the throttle or the throttle control in the "stop" position. If the engine installation permits, it's a good idea to let the engine idle, without load, for a short time before stopping it; this allows the engine temperatures to be reduced gradually. It is also good practice to operate the overspeed trip when stopping the engine, to check the operating condition of this device. Before tripping the overspeed trip, reduce the engine speed to low idling speed. Some overspeed trips reset automatically; in some installations, it

will be necessary to reset the overspeed trip manually before the engine can be started again.

In addition to the detailed procedures listed in check lists and manufacturers' manuals, the following steps should be taken after an engine has stopped:

1. Operate the independent, motor-driven, circulating-water pumps and the lubricating-oil pumps (if provided) while the engine is cooling (15 to 20 minutes).

2. Open the drain cocks on the exhaust lines; and those on the scavenging-air-inlet headers, if provided.

3. Leave open an adequate number of indicator cocks, cylinder test valves, or hand-operated relief valves to indicate the presence of any water in the cylinders.

4. See that the air pressure is off. If starting-air is left on, the possibility of a serious accident exists.

5. Close all valves.

6. Allow the engine to cool.

7. Drain the fresh water when freezing temperatures prevail, unless an anti-freeze solution is being used.

8. Clean the engine thoroughly by wiping it down before it cools. Clean the floor plates and see that the bilges are dry.

9. Report the need for maintenance to your leading PO. No matter how minor they appear to be, repairs must be made and troubles corrected.

Precautions

The specific safety precautions for a given engine must be obtained from the applicable operating instruction manual. In addition to these specific precautions and the general safety precautions given at the conclusion of this chapter, the following precautions should be observed when you are operating and maintaining a diesel engine.

RELIEF VALVES.—If a relief valve on an engine cylinder or on an air compressor lifts (pops) several times, the engine or air compressor must be stopped immediately;

the cause of the trouble must then be determined and remedied. Relief valves must never be locked in a closed position, except in an emergency. Pressure-relief mechanisms are fitted on all enclosures in which excessive pressures may develop. Strict compliance with designated adjustments on these mechanisms is essential.

FUEL.—Precautions should be taken to see that fuel is not pumped into a cylinder while valves are being tested or while the engine is being motored, since an excessive pressure may be created in the cylinders when combustion of the fuel takes place. When it reaches the injection system, the fuel should be absolutely free from water and foreign matter. The fuel must be centrifuged thoroughly before use; the filters must be kept clean and intact. Leaks of fuel into the lubricating-oil system must be avoided; otherwise, dilution of the lubricating oil will occur, with consequent reduction in viscosity and lubricating properties.

WATER.—Do not allow a large amount of cold water, under any circumstances to enter a hot engine suddenly. Rapid cooling may crack the cylinder liner and head or seize the piston. When the volume of circulating water cannot be increased and the temperatures are too high, stop the engine. In freezing weather, all spaces which contain fresh water and which are subject to freezing must be carefully drained, unless an anti-freeze solution is added to the water.

AIR.—When engines are stopped, all starting-air lines must be vented; serious accidents may result if pressure is left on. Intake air must be kept as clean as possible; accordingly, all air ducts and passages must be kept clean.

CLEANLINESS.—Cleanliness is one of the basic essentials in the efficient operation and maintenance of diesel engines. Clean fuel, clean air, clean coolants, clean lubricants, and clean combustion must be maintained.

Engines must be kept clean at all times, and steps must be taken to prevent the accumulation of oil in the bilges or in other pockets.

OPERATING INSTRUCTIONS FOR GASOLINE ENGINES

(General)

Gasoline engines vary as much as diesel engines in type, size, and design. No one set of operating procedures would apply equally to all gasoline engines. As in the case of diesel-engine installations, the detailed operating instructions for a specific gasoline-engine installation must be obtained from the applicable instruction manuals. In order to familiarize you with the operating procedures for gasoline engines, in general, the procedures for operating one type of boat installation are described in this section. Remember that the following procedures are given only as an example. The temperatures, pressures, and revolutions per minute given for this particular installation would obviously not apply to installations with different engines or different related equipment.

The power plant of the boat installation described consists of three gasoline engines. The engines have magneto-ignition systems with a battery-booster coil system for

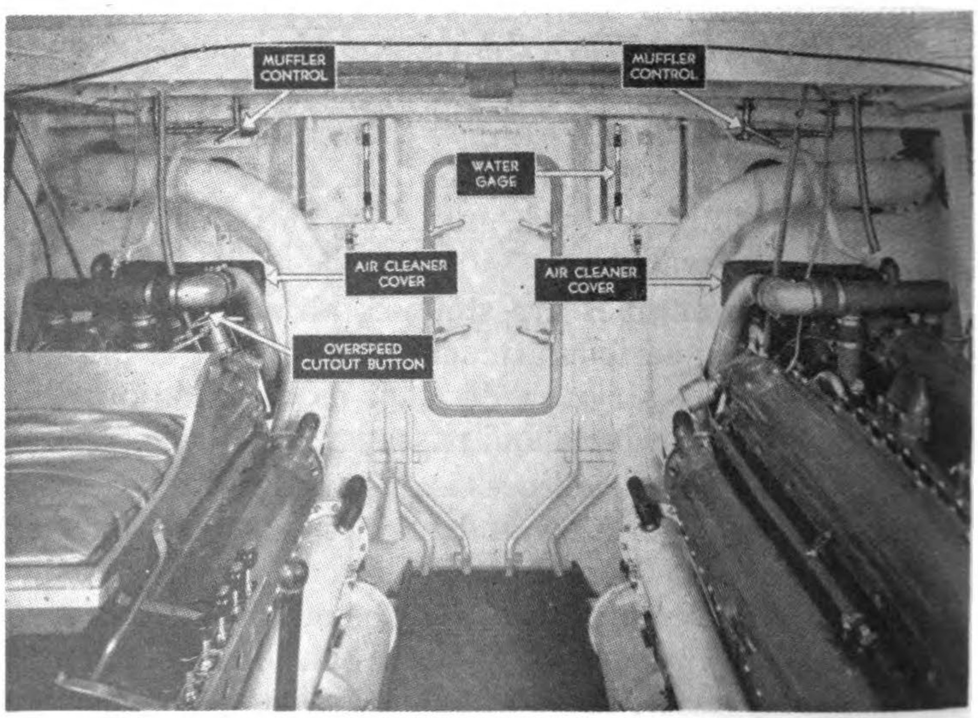


Figure 13–7.—Equipment arrangement in engineroom.

starting. (Refer to chapter 8.) The equipment arrangement in part of the engineroom is shown in figure 13–7; the main instrument panel is shown in figure 13–8.

For the purpose of this discussion, the procedure for operating the 3-engine power plant has been divided into five principal sections, the first of which is prestarting instructions.

Prestarting Instructions

There are a number of operations which must be performed before the engines are started. These operations are grouped under preliminary steps, instrument-panel operations, fuel-supply operations, and control-station operations.

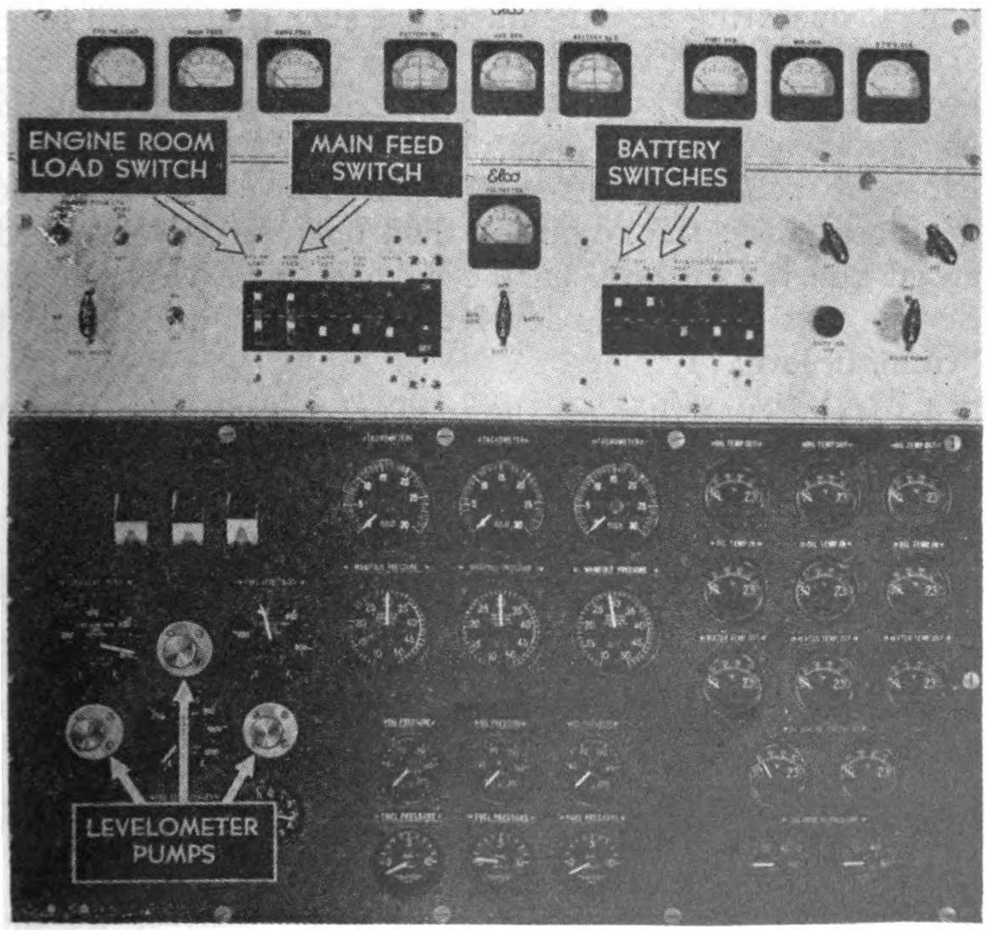


Figure 13–8.—Main instrument panel.

PRELIMINARY STEPS.—When the power plant is being prepared for starting, the first steps to be taken are:

1. Make sure that the ventilator covers have been removed, and that there is no gasoline vapor in the engineroom or in other spaces. Starting the engines when gasoline fumes are present in the engineroom might cause a serious explosion.

2. The fresh, cooling-water supply for all three engines should be checked by observing the water level in the glass gages (fig. 13–7) on the supply tanks.

3. Check the oil level in the glass gages on the supply tanks for all three engines. (In engines equipped with a bayonet gage extending into the crankcase, check the oil level against the scribed mark on gage. The scribed mark indicates the proper oil level when the engine is at rest. If operating circumstances are such that the oil level should be checked while the boat is under way, this can be done safely. First, however, a "running level" should be established on the gage. The running level is established by first bringing the oil up to proper level with the engine at rest; the engine is then operated at standard speed and the oil level on the bayonet gage is observed. Scribe a mark at this level on the gage, and label it "running level.")

4. Make sure that all the muffler controls (fig. 13–7) are in the OPEN position.

5. Rotate the cleaning handle of the edge-type oil OUT strainers through two complete turns (refer to chapter 10) to ensure free oil-flow when the engine is started. Repeat this procedure after every two hours of operation.

6. Remove the air-cleaner covers from the carburetor (fig. 13–7); make sure that the overspeed cut-outs on all three engines are in operating position, by pushing down on the red, "reset" buttons. (See figs. 8–20 and 8–21.)

7. Close the exhaust-manifold drain valves, at the reverse-gear end of all three engines.

INSTRUMENT-PANEL OPERATIONS.—After the preliminary steps have been performed, go to the main, battery-load switch-panel (A, fig. 13–9) and proceed as follows:

1. Turn to the ON position the two key-switches and the two toggle-switches which control the flow of current from the battery.

2. At the instrument panel, turn to the ON position the "Battery Number One" and "Battery Number Two" toggle-switches, as well as the "Engineroom Load" and the "Main Feed" toggle-switches (fig. 13–8).

FUEL-SUPPLY OPERATIONS.—The next step in the pre-starting procedure is the selection of the tank from which fuel is to be used. This is done as follows:

1. Check the level in the gasoline tanks by operating the levelometer pumps (fig. 13–8) until the gage needles stop rising.

Fuel should be selected from the wing tank which shows the highest level, so that the amount of fuel in the wing tanks is balanced as nearly as possible. (If both wing tanks are low, the center tank should be selected.)

2. After deciding which tank you will use, turn both the high- and low-suction tank-selector valves to the tank you have selected. (B, fig. 13–9.)

3. Turn the pointer of the low-suction fuel-line valve toward the electric, wobble pump; turn the pointer of the high-suction fuel-line valve away from the wobble pump. (C, of fig. 13–9.)

4. Be sure that the heater-feed valve and the auxiliary-generator feed valve are closed.

5. Open the three, gasoline-manifold valves (D, fig. 13–9). The procedure at the fuel-control panel is now complete.

CONTROL-STATION OPERATIONS.—After the operations at the fuel-control panel have been concluded, go to the control station (fig. 13–10) and proceed as follows:

1. Check to see that all three shifting-levers are in the NEUTRAL position.

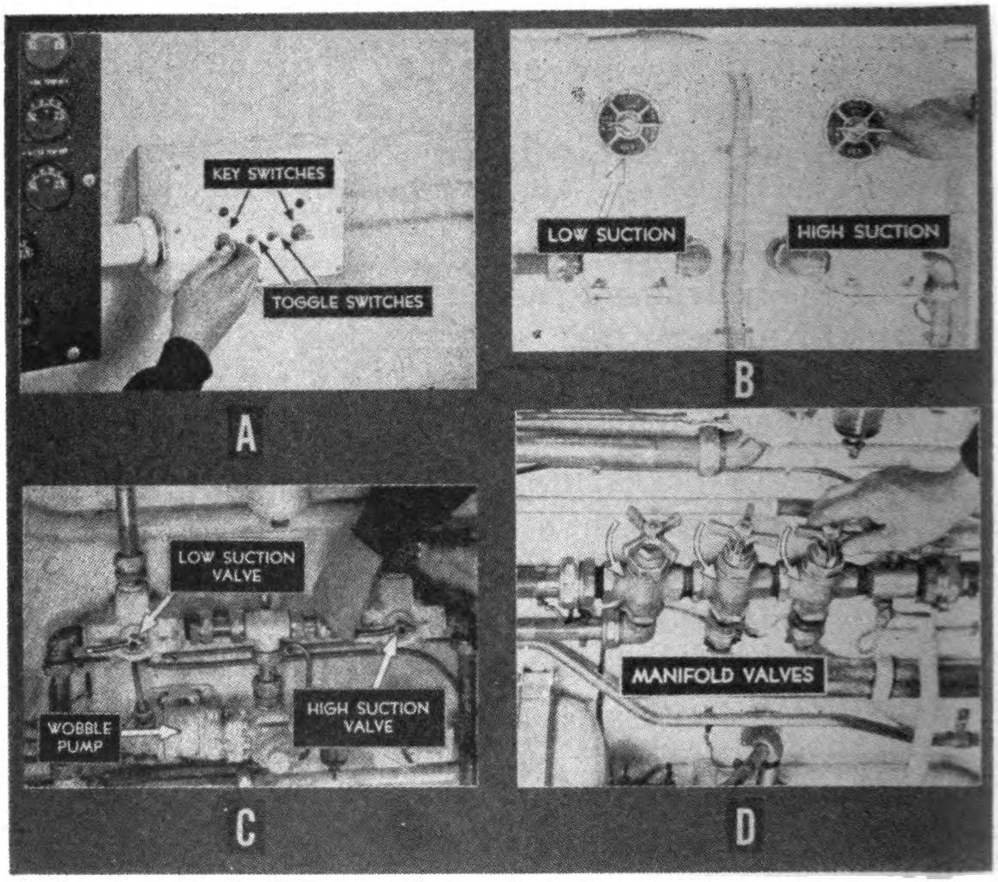


Figure 13–9.—Prestarting equipment checks.

2. Make sure that all the inlet scoops are open, and that the outlet scoops are closed. (See fig. 13–10.)

3. Make certain that the spark controls are pulled to the FULL RETARD position. (They must be in this position whenever the engine is started.)

4. Turn to the ON position the fuel-pump switch (A, fig. 13–11; and fig. 13–10) which operates the electric, wobble pump to build up initial fuel-pressure. (This will enable you to inspect the fuel system for leaks. If fuel leaks are found, they should be repaired; all traces of gasoline should be cleaned from the engineroom.) If the engines are not to be started at once, turn the fuel-pump switch to the OFF position when the inspection is completed.

5. Be sure that all three engines turn freely.

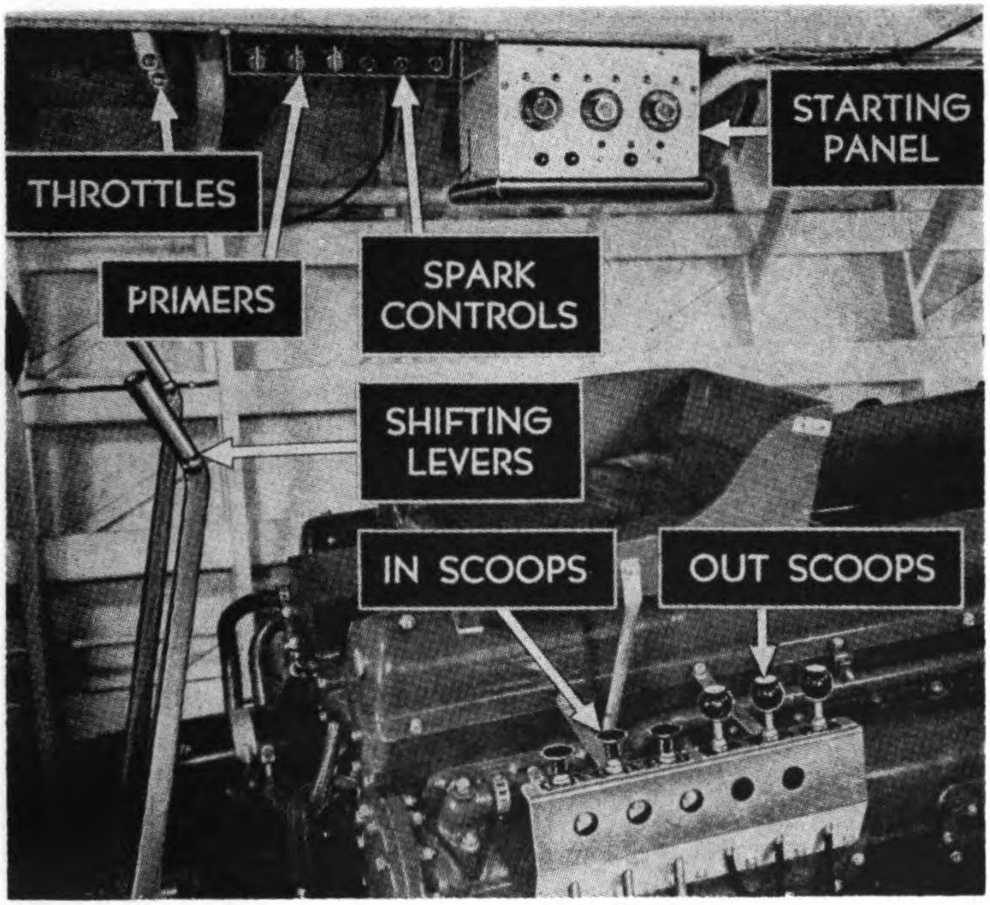


Figure 13–10.—Control station.

6. On the starting panel (fig. 13–10), turn to the ON positions the battery-parallel switch and the holding-coil switch, for the engine you are testing.

7. Turn the starting-and-ignition switch to the STARTER position (B, fig. 13–11). Be sure not to turn the switch to the STARTER-AND-COIL position; in this position, the switch would permit the engine to start. Be careful that the starting switch is not kept in the STARTER position for more than thirty seconds; keeping this switch in the STARTER position for a longer period of time may cause the starting motor to overheat, resulting in damage to the motor.

8. When you have finished your check, turn the battery-parallel and the holding-coil switches to OFF positions. (C, fig. 13–11.)

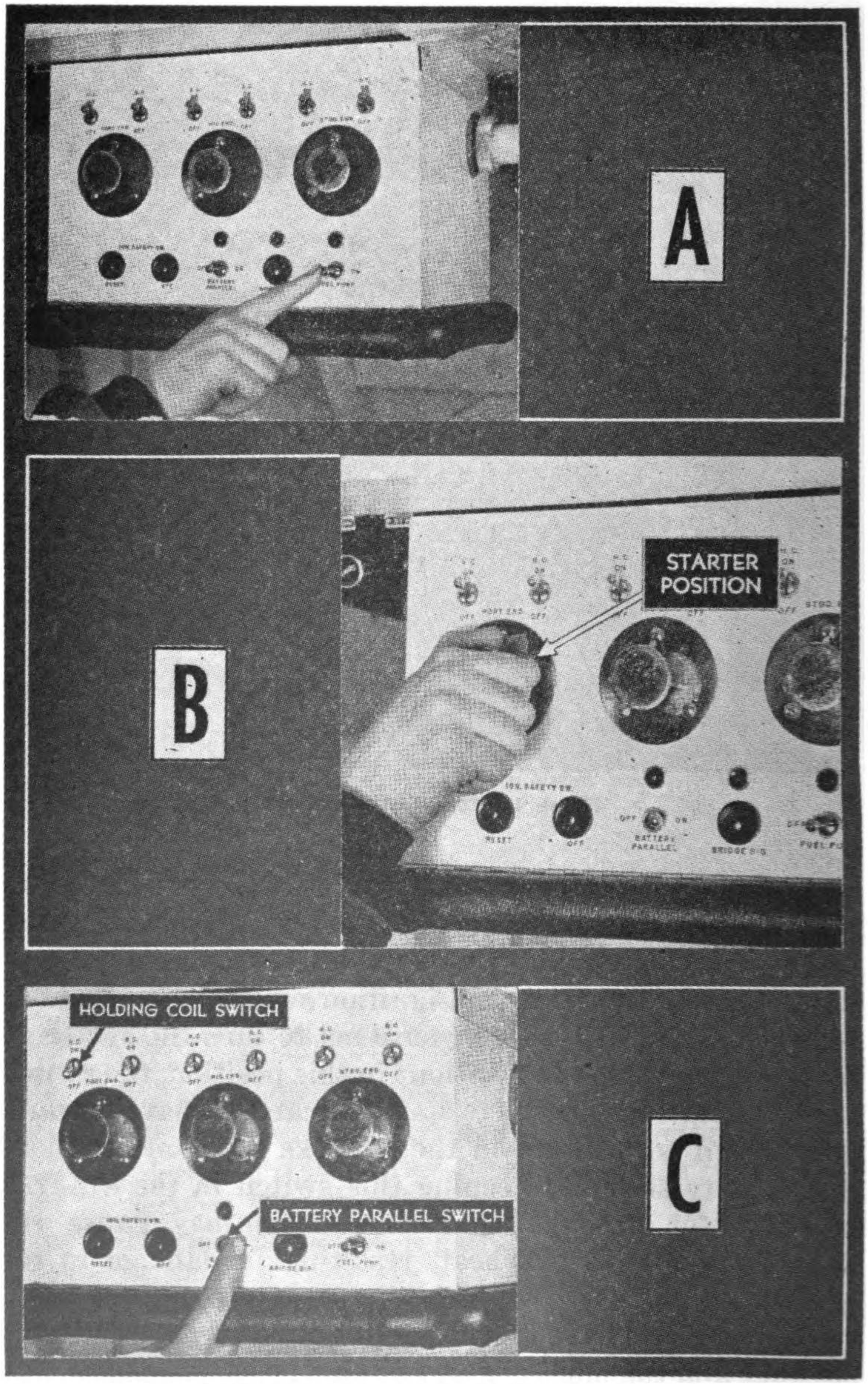


Figure 13—11.—Starting-panel operations.

Starting and Warm-Up Instructions

After the preceding series of preliminary operations has been completed, the engines will be ready to start. As soon as the starting signal is received, proceed as follows:

1. Snap to the ON position the three holding-coil switches and the three booster-coil switches on the starting-switch panel.

2. Then snap the battery-parallel switch to the ON position; this will give you the combined capacity of both batteries, for starting.

3. Press the reset button on the overspeed cutout to ensure that the ignition circuit is complete. (See MAGNETO-IGNITION OVERSPEED CUTOUT, chapter 8.)

4. Turn the fuel-pump switch to the ON position again. Now you are ready to start the engines, one at a time.

5. Open the throttle slightly. This will prevent flooding when the engine is warm. When the engine is cold, the throttle should be closed.

6. Use the primer, or choke, in extremely cold weather. Never use the primer, however, unless the engine is extremely cold; the rich mixture resulting from the use of the primer will usually cause hard starting, if the engine is not extremely cold. If the primer is to be used first, make sure that the throttle is closed; then give the primer several strokes to clear it of air, and use from two to six priming strokes after the pump takes hold. In cold weather, gasoline does not vaporize easily; the normal fuel-air mixture is, therefore, too lean for such weather and the engine will be hard to start. It is then necessary to use the primer, which will close the choke valve in the carburetor and induce a heavier flow of gasoline. The resulting fuel-air mixture is explosive and the cylinders will fire when it is supplied to them. Do not open the throttle too wide when starting; too much throttle will cause the engine to race. Choking the engine will produce a mixture which is too rich to ignite in the cylinders. If this happens, push the choke back into running position;

close the throttle; and turn the engine over for several seconds before attempting another start. In very cold weather, it may become necessary to warm up the carburetor and the intake manifold by wrapping rags around them and pouring boiling water on the rags.

7. Turn the starting-and-ignition switch to the STARTER position. Hold the switch in this position until the starter turns the engine up to maximum cranking speed.

8. Then turn the switch clockwise to the STARTER-AND-COIL position (A, fig. 13–12), until the engine starts. Do not hold the starting-and-ignition switch in the STARTER-AND-COIL position for more than thirty seconds; holding the switch in this position for a longer period of time is likely to overheat the coil and burn the points.

9. As soon as the engine starts, close the throttle; and turn the starting switch to the MAGS-INTAKE-AND-EXHAUST position. (B, fig. 13–12.)

10. Immediately check the oil-pressure gage on the instrument panel of the engine you are starting. If the oil gage does not show pressure after five seconds of operation, the engine should be stopped at once; it should not be restarted until the cause of the oil-pressure failure has been determined and corrected.

11. After the other two engines have been started and when all three oil gages show pressure, snap the electric fuel-pump switches and the battery-parallel switches to the OFF position; snap the three holding-coil and the three booster-coil switches to the OFF position.

12. No load should be put on the engines, that is, the boat should not get under way until the oil-inlet and water-discharge temperatures have reached 100° F. During the warm-up, feel the exhaust manifolds and pipes (C, fig. 13–12), to make sure that sea water is being circulated through them.

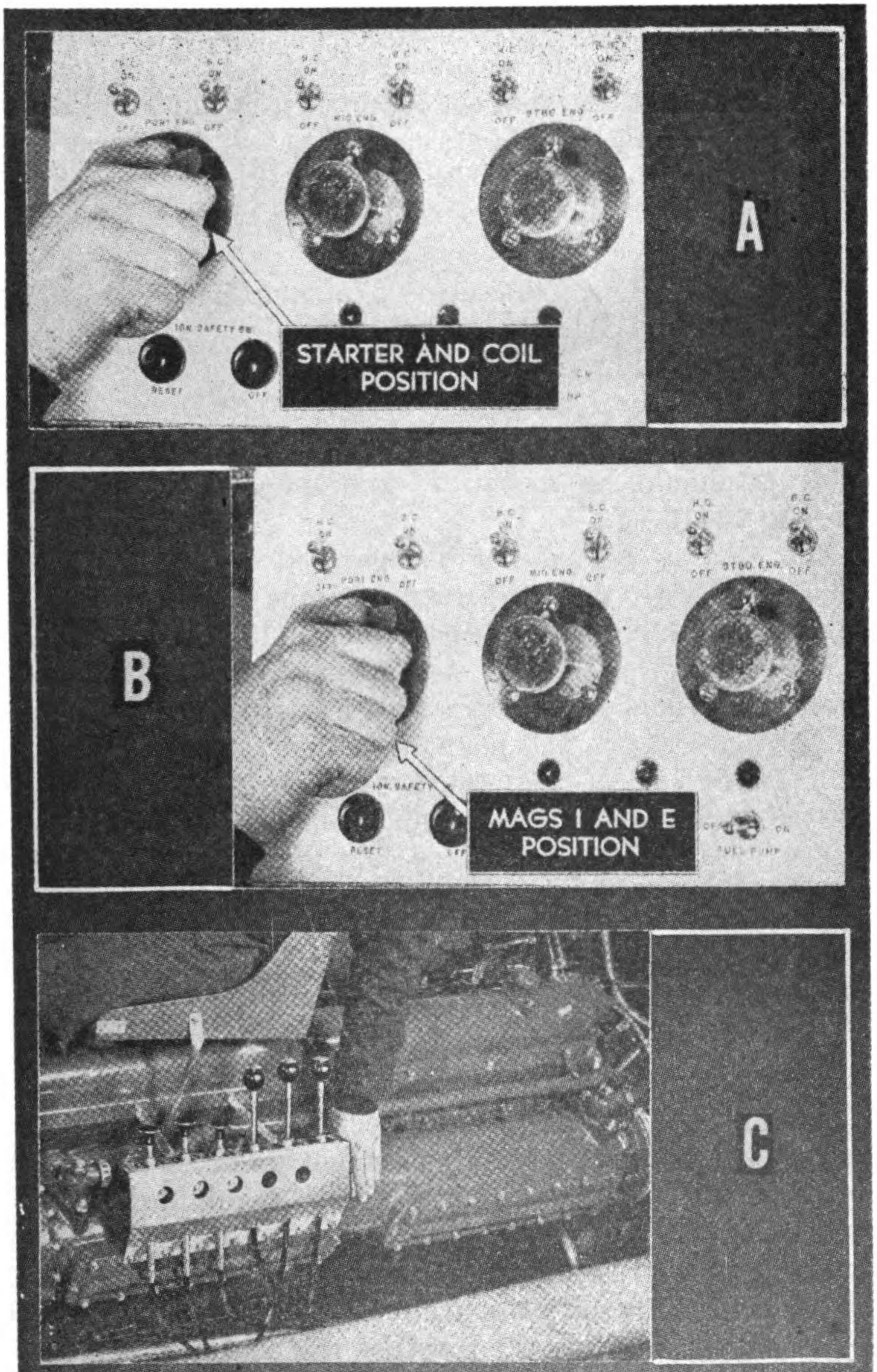


Figure 13–12.—Starting and warm-up operations and checks.

Under Way Instructions and Notes

The warm-up should be completed under way, whenever possible; this will shorten the warm-up time and will tend to reduce fouling of the spark plugs. As soon as the oil-inlet and the water-discharge temperatures have reached 110° F, the boat may be gotten under way. In getting under way, proceed as follows:

1. Operate the shifting gears to engage the drives. The shifting levers should be moved with a smooth, positive motion so that, at all times, the drives are either fully engaged or fully disengaged.

2. As soon as the boat gets under way, the out-scoop controls should be moved to the WIDE-OPEN position. (A, fig. 13–13.)

The engines should not be operated at speeds above 1000 rpm, until the temperature of the oil entering the engine (IN-TEMPERATURE) has reached 130° F. However, in case of emergency, the engines may be run at higher speeds, provided the oil pressure holds steady and does not go above 150 pounds per square inch.

3. When the IN-TEMPERATURE of the oil has reached 130° F and the temperature of the water at the engine discharge (OUT-TEMPERATURE) has reached 150° F, the engines may be run at full rpm.

4. As soon as the engine speed has reached 1200 rpm, the spark controls should be changed to the FULL-ADVANCE position. (B, fig. 13–13.)

5. While the boat is under way, all gages and instruments should be checked frequently.

OIL PRESSURE should be between 90 and 105 pounds per square inch, at all speeds. Any sudden or considerable variation above or below these limits should be investigated immediately. (This rule applies, in general, to all indications of pressure and temperature.) However, don't be alarmed if the oil pressure drops as low as 60 pounds per square inch when the throttles are closed rapidly.

OIL TEMPERATURES should also be watched constantly. Normally, the IN-TEMPERATURE will be held between

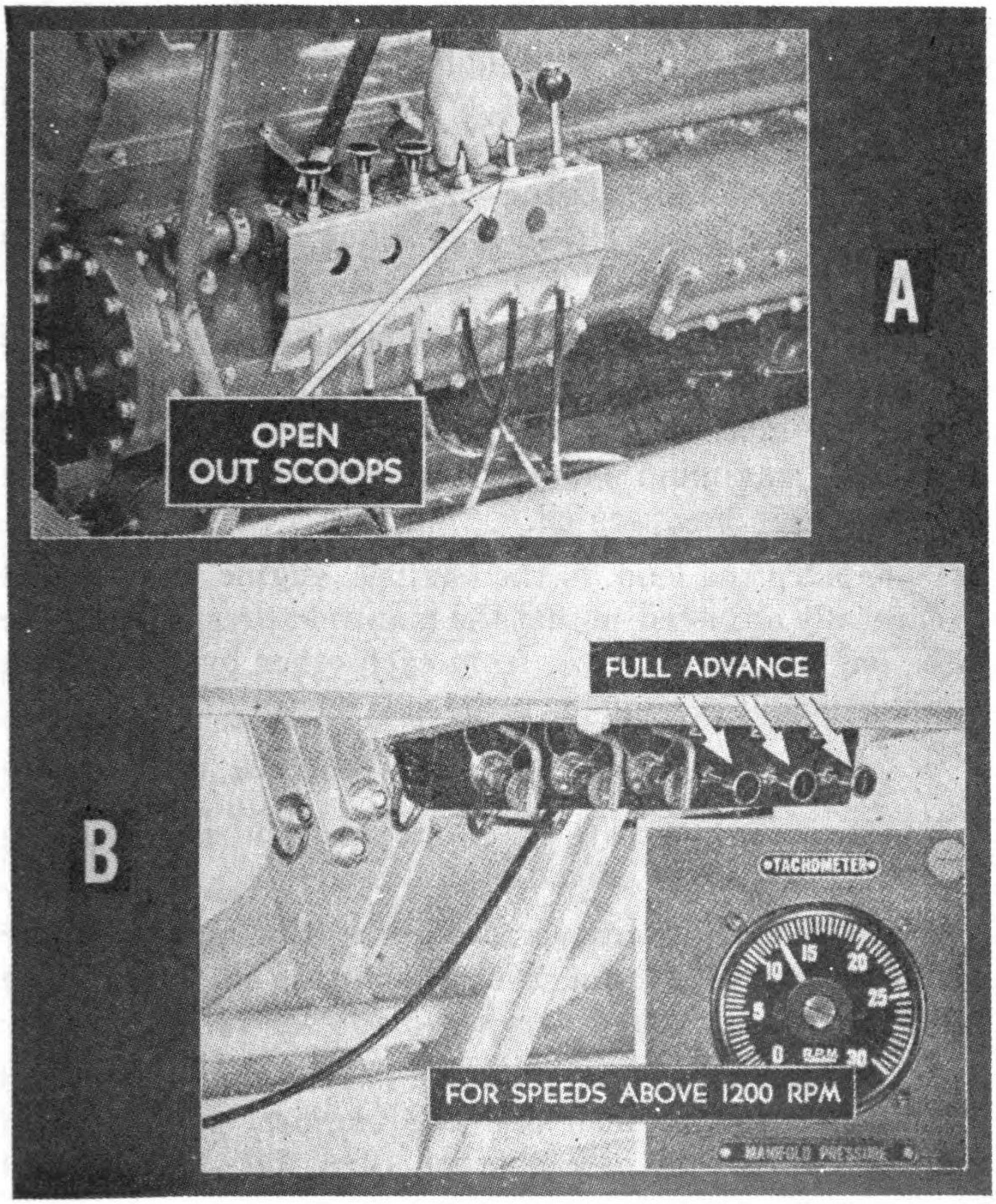


Figure 13—13.—Under way operations and checks.

130° F and 150° F by the thermostat. The OUT-TEMPERATURE will increase as the engine speed increases, ranging between 140° F and 200° F. However, an OUT-TEMPERATURE of around 200° should be reached only when the engine is operating at 2400 to 2500 rpm.

When the boat is under way, the in-scoops of the salt-water cooling system should be used to control engine FRESH-WATER TEMPERATURE. The out-scoops must be kept

wide open. The allowable OUT-TEMPERATURE for fresh water is 150° F to 170° F. Hold the discharge temperature of the water as close to 160° F as possible, however, for efficient operation. (In general, the discharge temperature of the jacket circulating-water should not be allowed to exceed 170° F in a closed system; or 130° F in an open system.)

MANIFOLD PRESSURE should be checked frequently while the boat is under way. The pressure gage readings should be checked against the manifold-pressure charts, which show the maximum allowable pressures at which the engines are to be operated.

To balance the load on the engines, engine rpm should be carefully adjusted so that the manifold pressures of the three engines do not vary from each other by more than one-half pound per square inch.

Stopping and Securing Instructions

When the engines are to be stopped and secured, the following procedure should be followed:

1. To stop the engines, turn the fuel-tank selector valves to the OFF position, thereby shutting off the gasoline supply; close the three gasoline-manifold valves.

2. As soon as the fuel pressure has dropped below two pounds per square inch and the engines begin to run roughly because of lack of fuel, turn the starting and ignition switches to the OFF position.

3. To secure the engines, open the drain valves in the exhaust-manifold end-covers; close all the in-scoops; make sure that the muffler controls are in the OPEN position.

4. Turn to the OFF position all switches on the instrument panel, and the switches on the main, battery-load switch-panel.

5. Replace the air-cleaner covers on all three engines; wipe down the engines, while they are still warm.

Operating Precautions

Certain precautions must be taken if the most efficient operation of a gasoline engine is to be obtained. These precautions will vary, depending upon the engine and the conditions under which it is operating. The specific operating precautions listed in operating instruction manuals must be observed. The following general precautions should be observed, when applicable:

1. Do not attempt sudden increases in speed by quickly opening the throttle wide. The engine suffers less when the throttle is opened gradually.

2. Do not make changes in speed by using the spark; such changes should be made by throttle regulation.

3. Try to avoid running the boat in shallow water, where mud and sand will be pumped into the engine cooling spaces. Clogged cooling spaces may cause the engine to run hot; serious trouble may arise from the overheating. (See chapter 14.)

4. A new engine, or one with new cylinders or pistons, should be run at reduced speed to permit these parts to wear in properly.

5. Do not tamper with the engine governor, if one is provided.

6. Do not back the engine at full speed, except in an emergency. In approaching a landing, a good seaman slows the engine at a distance, which depends upon speed and load of the boat, so that full speed astern is not necessary. Nothing ruins engine bearings and reverse-gear teeth as quickly as sudden backing at full speed.

7. Do not engage the clutch suddenly, since this places a strain on the clutch mechanism and the gearing. Engage the clutch slowly to start the propeller shaft turning, hold it in place for a few seconds, and then place it in the locked position. Any slipping in the clutch must be corrected promptly to prevent excessive wear of the clutch disk surfaces.

8. If any unusual noises develop during engine operation, investigate them at once. The cause of such noises

must be found and remedy effected; otherwise, engine parts may be extensively damaged. If necessary, the engine should be stopped.

Fuel and Fueling Precautions

The following information applies, in general, to all gasoline-engine installations; it applies more specifically, however, to boat-engine installations.

1. Do not permit gasoline to accumulate in carburetor drip-pans or in bilges.

2. Keep the bilges dry and well ventilated. In motor boats where an exhaust blower is provided for the engine-room space, this blower must be operated for at least five minutes before the engine is started.

3. Do not permit rags soaked with gasoline or oil to remain in the boat.

4. Smoking, lighting matches, and carrying open-flame lights (e.g., lighted oil lanterns) are strictly prohibited in power boats; they should not be permitted within one hundred feet of a boat which is engaged in fueling.

5. Carburetor intakes and crankcase breather pipes must be fitted with back-fire screens of approved type.

6. The electrical system of the engine must be inspected frequently to guard against grounds and sparking of commutator brushes.

7. Extreme care must be exercised not to spill gasoline into the bilges when fueling the boat.

8. During the fueling of motor launches and motor whale boats, the engine hood or casing must be open to permit a free circulation of air around the engine and thus prevent the formation of an explosive mixture inside the casing. Do not close the cover until the engine has been started and is operating in a satisfactory manner.

9. Only personnel engaged in the actual fueling operation should remain aboard the boat.

10. The controls of the built-in fire-extinguisher system must be ready for instant use.

11. Portable, CO_2 fire-extinguishers must be held in readiness alongside each fuel hose.

12. The main-battery switches must be in the OFF position.

13. A ground wire must be attached to the nozzle of the fuel-supply hose and to the fuel-tank filler-neck; all component parts of the filtering system must be grounded.

14. Boats should not be fueled at night or while close to one another, except in emergencies.

15. Never start an engine when there is a strong odor of gasoline in the engineroom.

Safety Precautions—General

In addition to following the specific safety precautions listed in the operating instructions for an engine, you must continuously exercise good judgment and employ common sense in taking steps to prevent damage to material and injury to personnel.

In general, you can aid in preventing damage to machinery by operating engines according to prescribed instructions; by observing all rules of cleanliness when handling the parts of an engine during maintenance or overhaul; by having a thorough knowledge of your duties; and by having a complete familiarity with the parts and functions of the machinery being operated and maintained. Damage to a ship or boat may be prevented by maintaining machinery so that the engines will be ready for service at full power in the event of an emergency; and by taking steps to prevent conditions which are likely to constitute fire- or explosion-hazards.

You can do a great deal to avoid personal injury by having a thorough knowledge of your duties; by the proper handling of tools, machines, and parts; by taking normal precautions around moving parts; by using safeguards at danger points; and by constantly being careful and thoughtful as you perform your duties.

QUIZ

1. With respect to engine lubrication, what is required when the jacking gear of a diesel engine is being used?
2. How are special devices used to aid in starting diesel engines in cold weather?
3. On the basis of the source of heat, name two types of air-intake heaters.
4. What fluid is generally used as an auxiliary fuel in starting diesel engines in cold weather?
5. Give two reasons why engine parts may be damaged if load is applied too suddenly to a diesel engine which has not reached normal, operating temperatures.
6. Name two conditions, in addition to damage to engine parts, which may occur if a diesel engine is operated for a long period of time at less than 30 percent power.
7. Name three symptoms which indicate that an engine is overloaded.
8. List five lubrication checks, or operations, which may be required during diesel-engine operation.
9. Identify the diesel-engine systems to which the following operating temperature ranges apply: (1) 100° —130° F; (2) 140° —170° F; (3) 140° —180° F.
10. Give two methods by which the temperature of engine cooling-water may be controlled.
11. When an automatic temperature-regulator is installed in the sea-water circuit of an engine cooling system, where is the bulb of the temperature-control element located?
12. To what does the term "critical speed" apply?
13. Why should an overspeed safety device be tripped when a diesel engine is being stopped after normal operation?
14. After a diesel engine is stopped, what is sometimes done to accelerate the cooling of the engine?
15. What should be done if the relief valve on a cylinder of an operating diesel engine lifts several times?
16. What precaution must be taken to ensure that an explosion will not occur when the gasoline-engine power plant of a boat is started?
17. Why does the bayonet gage in the lubricating-oil systems of some engines have two scribed marks?
18. If fuel for the gasoline-engine power-plant of a boat is available from two wing tanks and a center tank, which tank should be selected as a source of fuel when the power plant is started? Why?

19. When a gasoline engine is being checked for free turning prior to starting, why should the starting switch not be held in the START position for more than 30 seconds?
20. If a gasoline engine fails to start with the aid of the primer in extremely cold weather, what additional measure may be taken to facilitate starting?
21. When a gasoline engine equipped with a battery- and booster-coil starting system is being started, what parts, in addition to the starting motor, may be damaged if the starter switch is held in the START position for more than 30 seconds?
22. Give the advantages of completing the warm-up of the gasoline-engine power-plant of a boat after the boat is under way.

CHAPTER 14

MAINTENANCE OF ENGINE SYSTEMS

In order to keep an internal combustion engine in reliable operating condition, it is necessary that a systematic and well-planned program of periodic inspection and routine maintenance be followed. If such a program is followed, many difficulties can be detected and corrected before any serious casualty occurs. Specific procedures of inspection and maintenance to be followed will depend upon the engine involved. As in the case of operating instructions, detailed information must be obtained from the applicable instruction manuals. General information on a few of the maintenance routines for which you will be responsible is given in this chapter and in the chapter which follows.

MAINTENANCE SCHEDULES

Many of the engines in use in the Navy are maintained under what is known as the Progressive Maintenance Program. Under this program, a maintenance schedule is established for detailed inspections and adjustments to be made at such intervals that maximum operating efficiency of the engine is assured at all times. The requirements of progressive maintenance are in addition to the routine inspections, maintenance, and adjustments which are made whenever an engine is being started and operated. The program applies principally to engines in which the cylinder assemblies are separate units. After they have been in operation for a specified number of

hours, individual cylinder units and major accessories are disassembled, inspected, repaired, and reassembled. This method of maintenance and overhaul ensures that the entire engine will have been progressively inspected and overhauled by the time it has been in operation for the recommended period of time between major overhauls. In the case of engines with enbloc cylinder construction, the entire engine is inspected and repaired at one time.

The prescribed number of hours between maintenance and overhaul periods, the items to be inspected and repaired, and the procedures to be followed are provided in Progressive Maintenance Pamphlets and in manufacturers' instruction manuals. These publications are furnished with each engine installation. If the information presented in these publications is diligently studied and the recommended procedures followed, an engine installation will not require major engine-overhaul by a yard, base, or tender, except when items of repair requiring equipment not available to ship's force are needed, or in the event of major casualty.

ENGINEROOM TOOLS

Most routine adjustments and all repair work in the engineroom require the use of tools. Some are general purpose tools, such as hammers, wrenches, and chisels. Others—as examples, feeler gages for measuring very small clearances, and the tool used for compressing valve springs—are designed for special uses or even for one special job.

Many of the general-purpose and special-use tools and their uses have been fully described in the Navy Training Course *Basic Hand Tool Skills*, NavPers 10085. However, some general cautions about the use and care of tools should be considered. First of all, TAKE CARE OF YOUR TOOLS; many of them are not designed for rough treatment. Tools are part of your fighting equipment and, as such, are as important as the engines themselves. A ship can't carry a lot of spare tools, and much of the time

you'll be far from a supply base. If you break some of your tools, it may be a long time before you can get replacements.

There are plenty of ways to ruin tools; nearly all of them are the result of either carelessness or ignorance, for which there is no excuse. LEARN TO SELECT THE PROPER TOOL FOR THE JOB. Don't pry with screwdrivers or wrenches or chisels, and don't hammer with wrenches. The most expensive tools, and the hardest ones to replace, are the precision items, such as micrometers and special gages. Such tools must be absolutely accurate; if they are strained or bent or damaged, they'll give inaccurate readings. A feeler gage that has a "permanent wave" in it will indicate a clearance much smaller than the actual clearance. This could lead to engine breakdown if, for example, the false reading were made on a piston or bearing.

KEEP ALL TOOLS CLEAN AND IN THEIR PROPER PLACES. Accumulation of dirt can ruin such precision tools as micrometer calipers. If tools are left lying about on benches or on the deck, sooner or later they'll be damaged by someone stepping on them or by other tools being dropped on them. PUT TOOLS AWAY when you're through using them.

Lathes, drill presses, and grinders are typical of the major, power tools found in a machine shop. There is a big difference between knowing the functions of these tools and actually being able to USE the tools. Depending on the type of ship to which you are assigned, you may or may not be required to operate the machine shop equipment. The only way to learn how to use these machines is to go into the shop and learn, under proper guidance, on the machines themselves.

CARE OF FUEL AND LUBRICATING-OIL SYSTEMS

One of the most important factors in maintaining a trouble-free and efficiently operating engine is cleanliness of the fuel and of the lubricating oil. Unless these liquids enter the engine free of dirt and abrasives, the precision-

ground surfaces of bearings and the surfaces within the fuel injection system will be damaged. Every precaution has been taken by the manufacturer to provide a means for the removal of foreign particles before they enter the fuel and lubricating-oil systems. Both systems are equipped with strainers and filters. The types of filtering devices commonly found in internal-combustion engine installations have been described in chapter 10. If the strainers and filters in the fuel and lubricating-oil systems of an engine are properly maintained and are serviced regularly, little trouble should be encountered from foreign particles entering these systems. Your jobs will include cleaning strainers and changing filter elements.

Maintenance of Strainers and Filters

The strainers used in both the fuel and lubricating-oil systems are basically the same. Devices of both the metal-edge type and the wire-mesh type are used to remove coarse, harmful particles from the liquid being filtered. The filters used in the fuel and lubricating-oil systems are replaceable, throw-away elements, which are mounted in a casing. Filters, located downstream of the strainers, remove particles which are too small to be caught by the strainer.

MAINTENANCE OF STRAINERS.—Metal-edge strainers function efficiently, if the blade mechanism is turned at regular intervals and the strainer sump is drained periodically. If these minor, routine-maintenance operations are not performed, however, the blade mechanism may stick or become broken; proper cleaning of the strainer element will then be impossible. If the scraper handle is not turned frequently enough, particles will gradually lodge between the scraper blades and the metal edges of the strainer element. When particles are allowed to accumulate, the strainer may become so clogged that the handle either cannot be turned or can be turned only with great difficulty. To prevent this, the strainer handles should be turned once an hour during engine operation. To avoid introducing into the downstream or clean, side of the

strainer sludge dislodged from the strainer during scraping, the scraper handle should be rotated when there is no liquid passing through the strainer, if possible. Where duplex strainers are provided, the strainer to be scraped may be bypassed during the scraping operation. When only one strainer is provided and the engine cannot be stopped in order to interrupt the flow of liquid through the strainer during scraping, the strainer must be scraped once an hour even though liquid is passing through it at the time.

The foreign material trapped by the strainer will drop to the bottom of the case and collect there. The strainer is by no means a water trap, but it is capable of stopping small amounts of water from continuing on through the system. The strainer acts as a settling tank. Water or sludge in the sump of the strainer will tend to accelerate corrosion, or rusting, of the strainer and of the scraper elements. This will cause sticking. The sump of the strainer must, therefore, be drained at regular intervals. If instructions that state otherwise are not given, it is advisable to turn the scraper handle one-half turn at the end of every hour of operation, and to drain the strainer of all sediment or sludge daily.

It is usually impossible to make simple repairs to a strainer that has been broken by too forceful attempts to turn a handle that has stuck. When a strainer has been broken in this manner, it is generally necessary either to make extensive replacements of parts or to replace the entire strainer. It is quite possible, however, to prevent breakage of the shaft, handle, or blades and put the strainer back into operation when the handle is found to be stuck. At the first sign of sticking (evidenced by considerable difficulty in turning the scraper handle BY HAND), the strainer should be disassembled and cleaned. When the strainer is being cleaned, the element should first be removed; it should then be immersed in clean, noncorrosive solvent. The deposits should be removed from the metal plates and blades with a soft cloth or

brush. Then the element should be rinsed thoroughly in clean solvent and replaced.

The procedure for disassembling and cleaning a strainer will vary, to a degree, depending on the type of strainer and on the installation. The steps to be followed in cleaning one type of metal-edge, lubricating-oil strainer (fig. 14–1) are given here, as an example:

1. Remove the drain plug (A, fig. 14–1); and drain the strainer case, catching the drainings in a clean container.

2. The drained oil should be strained through a cloth or filter; it should be carefully checked for metal particles which may indicate trouble inside the engine. Any indication of metal particles in the engine oil should be called

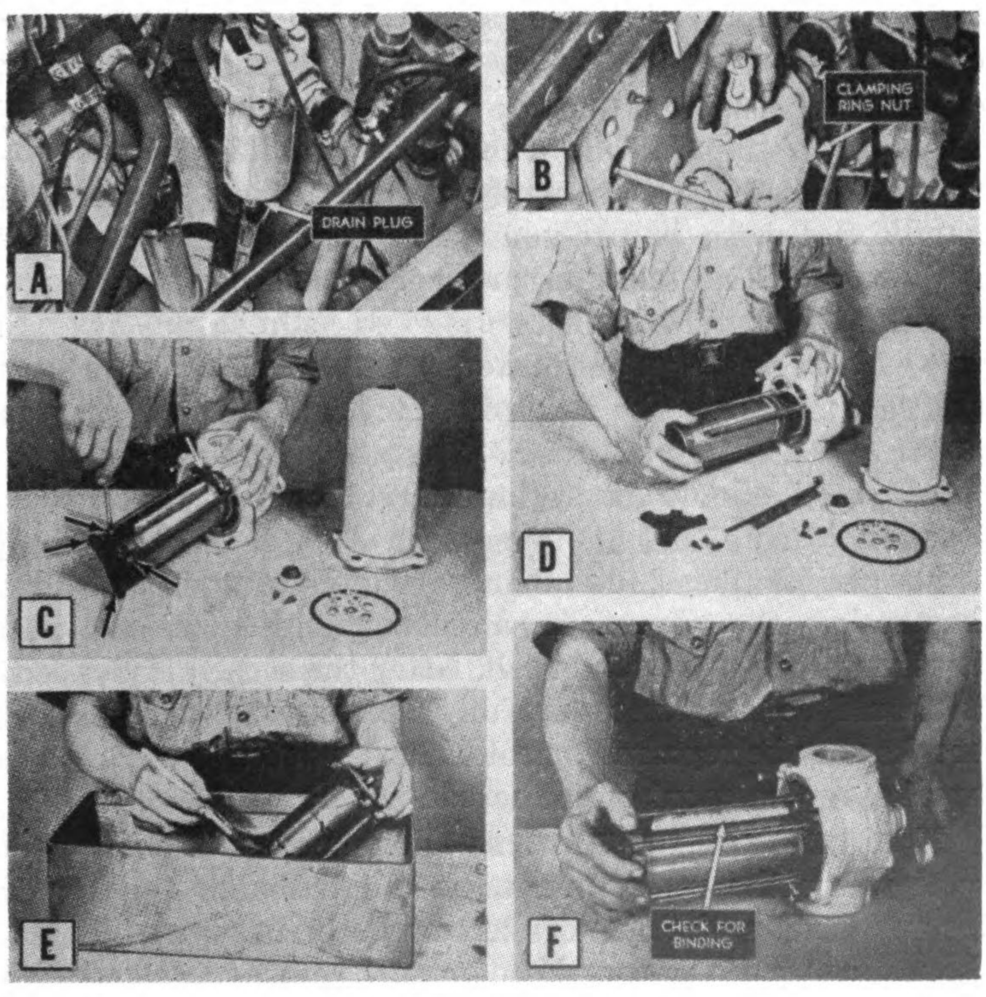


Figure 14–1.—Cleaning a metal-edge strainer.

to the attention of your leading PO. Metal particles may indicate abnormal wear on the bearings of the engine.

3. Unscrew the clamping-ring nuts (B, fig. 14–1). These nuts should be unscrewed evenly to avoid distorting the ring.

4. Unscrew the screws on the cleaning-knife frame.

5. Remove the screws which hold the bottom spider to the strainer-element support rods. (C, fig. 14–1.)

6. Pull the element out of the head (D, fig. 14–1). Be extremely careful not to damage the strainer element. If the element is damaged in any way, it should be replaced.

7. Wash the element (E, fig. 14–1) in a recommended solvent. Be careful that no dirt gets inside the element. Use a soft, lint-free cloth or a soft brush for cleaning the element; never use a scraper or a wire brush. (A scraper or a wire brush will damage the element.)

8. When the element is being reinstalled, be sure to tighten the screws uniformly; and to turn the cleaning handle clockwise, before you reassemble the case, to make sure that the element is properly lined up and is not binding (F, fig. 14–1).

9. Position the new gasket carefully when installing the case; tighten the clamping-ring nuts in the proper order and a little at a time, to avoid distorting the ring. These nuts should be tightened sufficiently to prevent leaks.

Screen, or mesh, strainers are generally cleaned by immersing the screen in a recommended solvent and brushing lightly with a brush. After the screen is cleaned, it should be inspected carefully for any ruptures. Small breaks may be repaired by soldering; when there are large breaks, replacement of the screen is necessary.

MAINTENANCE OF FILTERS.—For specific instructions concerning the replacement, on a particular engine, of filter elements, the size of element to be used, and installation instructions for the element, reference should be made to the engine manufacturer's instructions and to

directives issued by the Bureau of Ships. The following information applies, in general, to the filters used in both the fuel and lubricating-oil systems.

Filter elements should be replaced whenever they are clogged, regardless of whether or not the recommended number of hours of engine operation have elapsed since installation. The symptoms of clogged filters will vary in different installations. Each installation should be studied, and the probable symptoms anticipated. A clogged filter may be indicated by stoppage of liquid flow through the filter; by an increase in pressure-drop across the filter; by an increase in pressure upstream of the filter; or by excessive amounts of foreign material on the filter element, which can be observed when the filter is dismantled for inspection.

When the element of a filter is being changed, the case should be thoroughly flushed to remove all traces of foreign material; the new element should be positioned properly; and all gaskets should be replaced with new ones, if possible.

In emergencies, when new elements are not available and the engine must be operated, it may be possible to get limited additional service from a totally clogged filter element by washing it.

When a totally clogged element is to be washed, plugs (preferably corks; never paper toweling) should be placed in the ends of the element. If this is not done, dirt from the outside of the element will be washed into the downstream side of the element and will be carried into the injection equipment or bearings as soon as the engine is started. A filter which has been plugged for washing is shown in figure 14–2.

The element is immersed in clean, noncorrosive, cleaning solvent; and the deposits are then scrubbed from the outside of the element. It cannot be expected that this procedure will remove deposits from inside the element, to any great extent. When the cleaning process has been completed, and before the plugs are removed, all traces

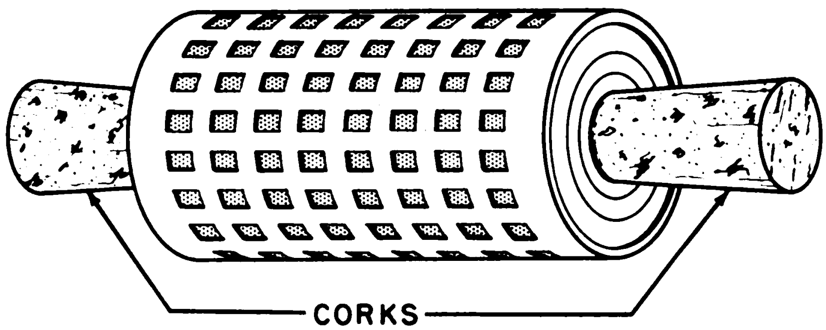


Figure 14—2.—Filter plugged for washing.

of cleaning solvent should be rinsed from the element with clean Diesel fuel. The plugs are then removed and the element reinstalled.

Oil Changes

In many large engine installations, the lubricating-oil system includes a purifier (see chapter 9), which removes the water and impurities which are not removed by the strainers and filters. Purifier-equipped engines can be operated usually without the necessity of an oil change. An oil change may be necessary on an engine equipped with a purifier, however, when there is excessive contamination of the lubricating oil by sea water; or when the acid content, the amount of sludge and foreign matter present in the lubricating oil, or the percentage of fuel dilution becomes excessive. Water contamination of the lubricating oil may be disclosed either by the cloudy appearance of the oil or by the presence of small droplets of water in a sample of the oil which has been shaken in a bottle. The extent of contamination by acid, and by sludge, and the extent of dilution must be determined by tests and analyses. Additional information on lubricating-oil tests is given in the training course, *Engineman 2*, NavPers 10540.

In an engine which is not equipped with a purifier, the oil must be changed after a specified number of hours of operation. For a particular engine, the interval of time between oil changes will be governed by such factors as the type of engine involved, the kind of oil used, and the

conditions under which the engine operates. Unless otherwise specified, the time between oil changes should not exceed 750 hours of operation for slow and medium-speed Diesel engines; it should not exceed 100 hours of operation for high-speed Diesel engines and gasoline engines. There are several conditions which may make it necessary to shorten the length of time between oil changes. These conditions are generally evidenced by corrosion of engine parts or by the appearance of the oil.

Since oils in the Navy-symbol 9000 series are noncorrosive, corrosion in engines using these oils will indicate that the oil has been used too long and, as a result, is characterized by high acidity, excessive sludge, etc.; that oil temperatures have been excessive; or that the engine has been run for some time with lubricating oil that has been diluted with fuel oil. When rust is found within the crankcase area of an engine, it is likely that the lubricating oil has been contaminated with water. Corrosion within the lubricating-oil system can be held to a minimum if, regardless of the number of hours of engine operation since the last oil change, the oil is drained and replaced with fresh oil whenever oil temperatures have been excessive, dilution with fuel oil is known to exist, or water contamination is discovered.

Steps must be taken to eliminate the necessity of frequent oil changes. Excessive oil temperatures and lubricating oil dilution with fuel oil can be minimized by operating an engine in strict accordance with applicable operating instructions. The dilution of lubricating oil with fuel can be further minimized by keeping fuel injection equipment or carburetors in proper adjustment and repair. Causes of lubricating-oil contamination by water must be determined and eliminated before fresh oil is placed in an engine.

MAINTENANCE OF ENGINE COOLING SYSTEMS

Since the purpose of an engine cooling system is to keep engine parts and working fluids at safe operating temperatures, too much attention can not be given to the

maintenance and care of the cooling system. Steps must be taken to prevent corrosion and to reduce the tendency toward scale formation in cooling systems. Heat exchangers and water jackets must be properly cleaned, whenever necessary; circulating pumps must be maintained in the best of operating condition. The information in this section deals with the prevention of corrosion by the proper care of zincs, the reduction of scale formation by fresh-water treatment, and the proper maintenance of heat exchangers. Information on the care of pumps is given in the next chapter.

Care of Zincs

The purpose, types, and use of zincs in the cooling systems of engines have been presented in chapter 11 of this training course. As pointed out, when dissimilar metals are connected together and immersed in an electrolyte, a simple galvanic cell is formed. The connection between the two dissimilar metals completes the electric circuit and current flows from one metal to the other, through the electrolyte. The metal from which the current is flowing to the electrolyte will tend to suffer rapid corrosion; the metal to which the current is flowing from the electrolyte will tend to be protected from galvanic corrosion. The direction in which the current flows depends on the chemical nature of the metals exposed to the electrolyte and also on such factors as the hardness of the metal and the cleanliness of the metal surfaces. Thus, if a single metal is immersed in an electrolyte and one part of the metal surface is harder than another part or cleaner than another part, there will be a flow of current from one part to the other; and galvanic corrosion will take place.

In a heat-exchanger application, sea water constitutes the electrolyte of the galvanic cell. If zincs are properly suspended within the water chests of a heat exchanger, current will tend to flow from the zincs to adjacent metal surfaces which are exposed to the sea water. The zincs

(plates or pencils) and not the heat exchanger surfaces corrode as the current travels from the surfaces of the zincs to the metal surfaces of the heat exchanger.

It is essential that good, metallic contact exist between the zincs and the metal of the heat exchanger in order that the electrical circuit will not be interrupted. All zincs in the sea-water circuit of an engine cooling system should be inspected at least once a month, and more often if necessary. At this time, the zincs should be thoroughly cleaned of corrosion to assure that an active, metallic zinc surface is exposed to the sea water at all times.

Before opening the sea-water side of a heat exchanger, be sure that all sea connections, including circulating-pump suction valves and overboard-stop valves, are tightly closed and secured against being accidentally opened; this is necessary to avoid the possibility of flooding. Before an access-hole cover is removed from a heat exchanger, the salt-water side of the heat exchanger should be drained; you can then be sure that all sea connections are tightly closed. If practicable, inspection plates should be replaced and temporarily secured whenever work is discontinued.

The removal of a zinc for inspection and cleaning is relatively easy. Pencil-type zincs are usually threaded into a mounting plug in the water chest of the cooler. In replacing this type of zinc, the plug is first unscrewed; the zinc can then be removed from the plug. When a zinc pencil is installed, the threaded joints should be made up securely to provide good, metallic contact and to avoid the possibility of the pencil becoming detached from the supporting plug. Plate-type zincs are usually removed from the cooler by first removing the cover (fig. 11–7) to which the zinc is attached. The zinc is removed from the cover by simply removing the securing bolt or nut.

The method of cleaning zincs will vary, depending upon the size of the cooler involved. In large installations, the cleaning of zincs is best accomplished by using a chipping hammer; or by taking a cut off the surface, in a lathe,

to remove the scale and expose the base metal. In most cases, however, the zincs in the salt-water circuit of an engine cooling system can be properly cleaned with a wire brush and a scraper.

It is advisable to remove a zinc from the cover plate, or pencil plug, so that the surfaces of contact can be thoroughly cleaned. All corrosion and scale must be re-

Figure 14–3.—New and used zincs.

moved. The cleaned zinc may be compared with a new zinc (fig. 14–3) to determine the extent of deterioration. By tapping a zinc you can tell whether it has been eaten away on the inside; if it has, it will have a hollow sound. Zincs which are more than one-half deteriorated should be replaced with new ones. After a zinc is cleaned, its surface should be bright in appearance, but not necessarily shiny.

Cleaning of Heat Exchangers

In addition to properly maintaining zincs, you will be required to clean the salt-water sides of lubricating-oil coolers and fresh-water coolers. The method of cleaning will depend upon the type of cooler. Shell-and-tube coolers

must be cleaned by mechanical means (chemical cleaning of this type of cooler is not authorized); coolers of the radiator and plate types must be cleaned by chemical means. Since chemical cleaning is generally accomplished by personnel other than ship's force, only information on the mechanical cleaning of shell-and-tube coolers is given in this training course. (Information on the chemical cleaning process is presented in *Engineman 1 & C*, NavPers 10543.)

If a cooler is to remove the excess heat from lubricating oil or from fresh water effectively, it is essential that the cooler be inspected periodically (usually at 30–60 day intervals) for excessive scale and foreign material. Excessive scale and accumulations of dirt reduce the efficiency of the cooler. Unless the cooler is properly cleaned, therefore, scale and dirt may accumulate on the tubes to such an extent that the cooler cannot remove enough heat to keep the cooled liquid within prescribed limits.

The accumulation of scale and dirt on the salt-water side of a cooler element is usually a gradual process. The presence of scale and dirt on the cooler tubes is usually indicated, depending on the use of the cooler, by a gradual increase in oil temperature or in fresh-water temperature. Either excessive accumulations on the tubes or clogging of the tubes is indicated by a gradual increase in the difference between the inlet and outlet pressures of the cooler. As the amount of scale increases, the quantity of sea water that must be circulated to obtain the same cooling effect will increase. This is due to the insulating effect of the scale coating that forms on the salt water side of the cooler. When this condition is suspected, the heat-exchanger element should be removed, inspected, and cleaned.

Scale will form on the salt-water side of a cooler during normal operation. This is because of the dissolved salts present in the water. Some of the factors which tend to increase the rate of formation of this scale are improper maintenance of zincs and operating the engine with a high

sea-water temperature. The sea-water discharge temperature should be maintained below 130° F. At higher temperatures, the amount of scale formation is considerably greater.

Cooler elements may become clogged with such material as marine life, grease, or sand. Such clogging greatly reduces cooler capacity. A considerable increase in the difference between inlet and outlet pressure of the heat exchanger is a reliable indication of the fact that the element of the heat exchanger is becoming clogged. Cooler elements may become clogged through faulty operation of the sea water strainer; improper lubrication of pumps; or, in the case of oil coolers, a leaky element.

Sea water strainers are provided to prevent the entrance of fish, seaweed, sand, etc., into the circulating system. These strainers must be replaced or repaired when the screens become punctured or otherwise incapable of preventing entry of dirt into the system.

Many sea-water pumps are provided with grease cups for bearing lubrication. Turning such grease cups down too often may result in the grease being squeezed into the water being pumped. This grease will be carried into the cooler element and deposited there. The film of grease thus deposited will greatly reduce the capacity of the cooler. Sea-water pumps should be lubricated as specified in their instruction manuals.

A hole in the element of the oil cooler will allow the passage of lube oil into the water which is used for oil cooling. Some of the oil introduced into the water may be deposited on the water side of the cooler elements. The film of oil so deposited will act in the same manner as the grease film discussed above.

Leaks in oil coolers should be repaired as soon as possible. A vigilant lookout should be maintained for signs of oil or grease in the fresh-water system. If oil or grease is present, the source of the contamination should be located and eliminated.

When symptoms occur that indicate that excessive

amounts of scale or accumulations of dirt are forming on the salt-water side of a cooler, the element should be removed and cleaned. For ordinary cleaning of a cooler element (shell-and-tube type), an air lance should be pushed through each tube, the tube sheets should be washed clean, and all foreign matter should be removed from the water chests. In cases of more severe fouling, a water lance should be used instead of an air lance. In cases of extreme fouling, due to oil or foreign material, a rotating-bristle brush may be run through each tube; or soft rubber plugs (if available) may be driven through the tubes by an air or water gun. A water lance is then used to remove any remaining foreign material from the tubes.

Care should be taken that no abrasive tools capable of scratching or marring the tube surface are used. Wire brushes, or metal scrapers should never be used. Air and water lances and other cleaning equipment and procedures must be used carefully to avoid damaging the element. The cleaning of a cooler element will be much more effective and more easily accomplished if the cleaning is done before the accumulations on the surfaces of the element have had time to dry and harden.

The oil sides of shell-and-tube coolers of the removable tube-bundle type can be cleaned by removing the tube bundle and washing it with a jet of hot, fresh water. Care should be taken to dry the tube bundle thoroughly prior to reassembly. It should be noted, however, that with proper attention to purification and filtering of the oil, cleaning of the oil side of this type of cooler should seldom be necessary.

The fresh-water side of a water cooler will not corrode or become coated with scale as rapidly as will the salt-water side. This is because only distilled water or the cleanest water available is used in a closed, or fresh-water, cooling system. When distilled water is not available, the water used must be treated. Appropriate chemicals in proper amounts are added to the fresh water of

an engine cooling system to retard corrosion and to prevent the precipitation of scale-forming salts. Fresh-water treatment for engine cooling systems is described in the section which follows.

Fresh-Water Treatment and Tests

As a Fireman, you have become familiar with the many uses of fresh water aboard ship. You have become aware of the fact that all fresh water aboard ship, regardless of its use, must meet a high standard of purity. You have been introduced to some of the tests and treatments used in maintaining water at a high level of purity.

The purity of the water used in the closed circuit of an engine cooling system must be maintained at a high level in order to prevent the formation of scale and to control corrosion within the cooling system. These undesirable conditions can be prevented by filling the cooling system with distilled water or water with zero hardness and by treating the water so that the alkalinity and the sodium chromate and chloride concentrations are maintained within specified limits. The information in this section deals with the treatment of the water used in the closed circuit of an engine cooling system; and with the tests used to determine the effectiveness of the treatment.

NEED FOR FRESH WATER TREATMENT.—All water contains some impurities. Impurities dissolved or suspended in the water of an engine cooling system can cause trouble in the system by forming scale and by causing corrosion. Generally, scale forms only on the hot surfaces in the internal passages of the engine cooling system, and not throughout the system.

The formation of scale within the cooling system of an engine is caused primarily by certain sulphates of magnesium and calcium. Since these sulphates are present in sea water, and since cooling water for shipboard engines is generally distilled from sea water, some slight contamination of the cooling water must always be expected. However, the use of distilled water in the cooling system

of an engine simplifies the control of the scale-forming salts.

Steps must be taken to PREVENT THE FORMATION OF SCALE because scale is a very poor conductor of heat. If it is allowed to accumulate in the cooling system of an engine, the scale will prevent the proper transfer of heat from the hot engine parts to the cooling water. Improper heat-transfer, particularly uneven heat-transfer, causes stresses to be created in the affected parts; these stresses may cause cylinder liners, heads, and other parts of the engine to crack. If the water in the cooling system of an engine is properly treated, scale formation will be prevented and casualties caused by improper heat-transfer will be less likely.

Unless the water used in the cooling system is properly treated, the internal surfaces of the cooling system may become pitted or eaten away by corrosion. Such corrosion generally results from acidity of the water and oxygen dissolved in the water.

Corrosion in the cooling system of an engine may lead to cracks in liners and heads, and may cause serious damage to other parts of the cooling system. The CONTROL OF CORROSION in an engine cooling system can be accomplished by the use of proper water-treatment.

CHEMICALS FOR WATER TREATMENT.—The treatment of the water in an engine cooling system requires the use of chemicals to maintain the alkalinity and the sodium chromate concentration of the water at specified levels. If the alkalinity and the sodium chromate concentration of the water are properly maintained, scale formation and corrosive action will be greatly reduced. It should be kept in mind, however, that the water treatment discussed in this chapter is a preventive treatment only; it will not remove scale which has already formed in the cooling system.

The method of fresh-water treatment described here should be used in all internal combustion engines which have closed, fresh-water, cooling systems.

The chemicals used in the treatment of engine cooling water are BOILER COMPOUND and SODIUM DICHROMATE. These chemicals, in solution, tend to prevent the formation of scale and to control corrosive action. The use of boiler compound and sodium dichromate to counteract the action of impurities in engine cooling water is commonly called the "chromate boiler-compound" or "alkaline chromate" treatment.

The boiler compound reacts with the salts which would otherwise cause scale; it also maintains the water in a slightly alkaline condition. This alkalinity tends to counteract acid corrosion. While the boiler compound is acting to prevent scale formation and to maintain alkalinity, the sodium dichromate is acting to maintain sufficient sodium chromate in the water to control other forms of corrosion. Sodium dichromate can be converted to sodium chromate only when the recommended alkalinity of the water is attained as a result of the boiler-compound treatment.

INITIATING THE WATER TREATMENT.—Before the "chromate boiler-compound" treatment is used, the water system of the engine should be thoroughly cleaned and flushed out with fresh water. The system is then filled with clean, fresh water (preferably distilled water). If available instructions do not indicate the proper chemical dosage for a specific engine, it will be necessary to determine the capacity of the complete cooling system (in gallons of water) before the proper dosage of chemicals can be determined.

For each 100 gallons of cooling water to be treated, add three-fourths of a pound of sodium dichromate and 2½ pounds of boiler compound, dissolved in approximately a gallon and one half of warm distilled water. This solution is usually added to the cooling system at the expansion tank.

The solution is circulated through the system for at least ten minutes. Then, a 1½-pint sample of the treated water is drawn off for testing and is allowed to cool to at

least 80°F. When the sample has cooled sufficiently, conduct tests to determine the alkalinity and the sodium chromate and chloride concentrations of the treated water.

TERMS AND UNITS RELATED TO WATER TESTS.—The condition of the treated water, as revealed by these tests, is described in various terms and units. These standard terms and units are used in recording information regarding the tests, and in making reports.

The term used to identify the alkalinity of the treated cooling water is *pH*; the degree of alkalinity is indicated by a number following the term *pH*; for instance, *pH* 7, *pH* 8, etc. Since acidity decreases as alkalinity increases, the *pH* factor is also an index of acidity. When the alkalinity test is performed, the test sample will acquire a color which indicates the degree of alkalinity of the treated water: a yellow color indicates a *pH* value of less than 8 (7 is neutral); an orange color indicates a *pH* value between 8 and 10; and a greenish-purple color indicates a *pH* value of more than 10. The degree of alkalinity (*pH*) of the water, as indicated by color, is the basis for adjusting the amounts of the chemicals used in the treatment.

The concentration of sodium chromate and chlorides in a test sample of treated water are indicated in terms of PARTS PER MILLION (ppm). Parts per million is a weight-per-weight unit denoting the number of parts of a specified substance in a million parts of water. For example, 58.5 pounds of salt in 1,000,000 pounds of water represent a concentration of 58.5 parts per million (ppm). Note, also, that 58.5 ounces of salt dissolved in 1,000,000 ounces of water, or 58.5 tons of salt dissolved in 1,000,000 tons of water, represent the same concentration—that is, 58.5 ppm.

CHEMICALS AND EQUIPMENT FOR THE TESTS.—The chemicals and equipment used in preparing the test solutions and in performing the alkalinity and chloride tests are shown on page 510.

Sodium thiosulfate
Potassium iodide
Sulfuric acid solution
Soluble starch
Corrosion control indicator
Silver nitrate
One 10-milliliter (ml) graduated cylinder
One 100-milliliter (ml) graduated cylinder
One porcelain casserole
Aspirator-bulb assembly
One 10-milliliter (ml) burette
Two liter bottles—one for silver nitrate and one for thiosulfate.
One 8-ounce glass-stoppered bottle
One 50-milliliter (ml) "TK" dropping bottle
One 50-milliliter (ml) dropping bottle
Glass rods
One 150 milliliter (ml) beaker.

SOLUTIONS USED IN THE TESTS.—Some of the chemical solutions used in performing the water tests have to be prepared from stock chemicals; others are received ready for use. The solutions which have to be prepared are the sodium thiosulphate solution, the potassium iodide solution, the reagent silver nitrate solution, and the starch solution. Individuals charged with the responsibility of preparing the necessary solutions should use the chemicals and equipment listed in the preceding section and proceed as follows:

The SODIUM THIOSULPHATE SOLUTION (0.18N) is prepared by transferring 44 grams (gms) of sodium thiosulphate crystals to a clean, liter (thiosulphate) bottle; and then filling the bottle, to the mark, with distilled water. Stopper the bottle and then shake it until the crystals are dissolved. Label the bottle: "Sodium thiosulphate solution (0.18N), ml $\times$ 200 $=$ ppm sodium chromate in 50 ml sample." Remove the stopper and fit a burette and aspirator bulb assembly into the mouth of the bottle.

A fresh solution of sodium thiosulphate should be prepared every three months.

The POTASSIUM IODIDE SOLUTION (10%) is prepared by transferring 25 gms of potassium iodide crystals to a clean, 8-ounce bottle; and filling the bottle, to the neck, with distilled water. Stopper and shake the bottle until the crystals are dissolved. Label the bottle: "Potassium iodide solution (10%)."

In storage, the potassium iodide solution may develop a yellow color (due to free iodine in the solution). If the solution does develop a yellow color, add sodium thiosulphate solution (0.18N), a drop at a time, until the color disappears.

To prepare the STARCH SOLUTION, first place about 50 ml of distilled water in a 150-ml beaker and bring the water to a boil. Then sprinkle about a half-gram of soluble starch into the boiling water. Stir the boiling solution with a glass stirring rod for about one minute. Remove the beaker from the heat and allow the solution to cool. When it has cooled sufficiently, pour the solution into a clean, dropping bottle and label: "Starch Solution." Starch solution is subject to spoilage and should be made up fresh once a week; or whenever mold growth is noted in the solution.

Preparation of the REAGENT SILVER NITRATE SOLUTION (0.0563N) is accomplished as follows: weigh 9.57 grams of chemically pure silver nitrate on a clean balance pan; wash the weighed crystals into a liter volumetric flask with a stream of distilled water; when the crystals have dissolved, dilute the solution to one liter and transfer it to a glass-stoppered bottle. Label the bottle: "Reagent silver nitrate solution (0.0563N)."

The chemicals furnished ready for use are the SULFURIC ACID SOLUTION and the CORROSION CONTROL INDICATOR SOLUTION. Fill a clean, "TK" dropping bottle with the sulfuric acid solution; and fill a clean, dropping bottle with the solution of corrosion control indicator. Each bottle should carry a label indicating its contents.

SAFETY PRECAUTIONS.—When chemicals come in contact with the skin, they may cause injuries which are generally referred to as chemical "burns." For the most part, these injuries are not caused by heat but by direct chemical destruction of the body tissues. The results are painful sores and, frequently, infection. For this reason, you should handle the sulfuric acid solution and the sodium dichromate with care.

Sulfuric acid will cause injury more quickly than sodium dichromate. However, sodium dichromate, in dry form or in concentrated solution, will cause painful "chrome sores" if it is in contact with the skin for a prolonged period of time. You should take every precaution to avoid contact with either the acid, or the sodium dichromate in any form. If contact should be made, the affected skin areas should be thoroughly washed with soap and large amounts of clean, cool, fresh water.

WHEN TO PERFORM TESTS ON TREATED WATER.—Engine cooling water should be tested once each day when the sodium chromate treatment is being initiated or when the cooling system has been completely recharged. The interval between tests may be increased (at the discretion of the Engineer Officer) to a maximum of one week when tests indicate that the concentrations of sodium chromate and of boiler compound will not drop below the minimum limits of 900 ppm and *pH* 8; respectively, between tests. Tests should also be made whenever chemicals are added to the treated water for the purpose of adjusting the alkalinity or the sodium chromate content.

THE ALKALINITY TEST.—To test the alkalinity of the treated water, place a 10-ml sample of the water in a clean casserole. Add three drops of corrosion control indicator; stir well with a glass rod. The resulting change in color of the solution indicates the alkalinity (*pH*) of the treated water, and also indicates whether the amount of boiler compound applied in the initial treatment is adequate.

If the sample turns yellow (*pH* of less than 8), the water-treatment solution contains an insufficient amount

of boiler compound. To adjust the alkalinity of the water, add boiler compound, in amounts of not more than ½ ounce at a time, until the color of the test sample is orange.

An orange color in the initial test sample is an indication that the boiler-compound content is satisfactory, and that the alkalinity is sufficient to counteract acidity and to prevent scale formation.

If the corrosion control indicator causes the test sample to turn greenish-purple the treated water has an alkalinity of more than *pH* 10. This indicates that the amount of boiler compound in the sample is excessive. The procedure to follow when the alkalinity of water is excessive is covered in connection with the sodium chromate test, which is described next.

THE SODIUM CHROMATE TEST.—As the first step in determining the concentration of sodium chromate in treated water a 50-ml sample of the cooled, treated water is placed in a clean casserole. Then, 5 ml of potassium iodide solution and 15 drops of sulfuric acid solution are added to the sample. The mixture, blue in color, is stirred with a glass rod for about two minutes. Add about 1 ml of starch solution. Then add sufficient sodium thiosulfate solution (use burette) one drop at a time until the blue color disappears.

Record the volume (in ml) of sodium thiosulfate solution added; multiply this value by 200 to obtain the concentration, in parts per million, of sodium chromate in the treated water.

It is important to maintain the sodium chromate concentration between 900 and 1100 ppm. If the concentration drops below 900 ppm, corrosion may take place. When the concentration drops to 900 ppm and the alkalinity of the water is satisfactory (yellow—*pH* 8-10), two ounces of sodium dichromate and one and a half ounces of boiler compound should be added to each 100 gallons of cooling water. If the alkalinity of the water is too high (green—*pH* of more than 10), omitting the

boiler compound from the charge will effect reduction of the alkalinity. If a retest of the water indicates that the alkalinity is still high after the sodium dichromate has been added alone, one of two procedures may be followed.

One procedure involves draining about one-fourth of the water from the cooling system; then, refilling the system with fresh water and adjusting the sodium chromate concentration. An alternate method requires that the cooling system be drained completely, and then refilled. The water is then treated to establish the sodium chromate concentration between 900 and 1100 ppm and the alkalinity of the water between *pH* 8 and 10. Check with your leading PO or your Engineer Officer as to the method preferred aboard your ship.

THE CHLORIDE TEST.—The determination of chloride concentration is made on a cooled, 100-ml sample of water in a clean casserole. Stir the sample continuously as you add the reagent silver nitrate solution from the burette; continue adding the reagent until a faint orange color appears throughout the solution. The rate at which the silver nitrate solution is added should be reasonably constant during the early part of the titration; it should be gradually reduced as the end point is approached. The burette reading, in milliliters, multiplied by 20 is the chloride content of the sample, expressed in parts per million.

The concentration of chlorides in engine cooling water should always be less than 100 parts per million. If tests indicate that this limit has been exceeded, the entire system should be drained; and the cause of the sea-water leakage should be located and remedied. The system should then be refilled with fresh water and the water treated to obtain the proper chloride concentration.

WHAT TO DO IN THE ABSENCE OF TEST FACILITIES.—It is possible that test facilities for determining the condition of engine cooling water may not be available. In the absence of test facilities, the alkalinity and the sodium chromate concentration of the water can generally be main-

tained within satisfactory limits by carrying out the following procedure:

1. Drain and flush the cooling system at intervals of not more than three weeks.

2. Recharge the cooling system with fresh water and a treatment solution which is the same as that specified for the initial fresh-water treatment.

3. Maintain a minimum of 900 ppm of sodium chromate by adding the chemical in the amounts prescribed by your Engineer Officer. The amounts prescribed will be based on experience.

4. Draw the samples of the treated cooling water and submit them for analysis to the nearest Naval shipyard, tender, or advanced base laboratory.

When treating cooling water, in the absence of test facilities, it is well to remember that it is less dangerous to have too high a concentration of sodium chromate than to have too low a concentration. By careful use of sodium dichromate, or boiler compound, or both materials, you will be able to maintain desirable conditions in the fresh-water cooling circuit.

SAFETY PRECAUTIONS

Many of the precautions listed in chapter 13 are equally applicable when maintenance work is being performed. Several precautions have been included with related information in this chapter. In addition to the applicable precautions listed in this course, the prescribed precautions listed in manufacturers' manuals must be observed when maintenance work is being performed. An example of one such precaution that is given in all maintenance manuals for fuel-injection equipment is, KEEP HANDS AWAY FROM THE SPRAY WHEN FUEL INJECTORS ARE BEING TESTED. When an injector or nozzle tester is being used, it must be remembered that the penetrating power of the oil spray is sufficient to drive oil through your skin. Fuel-oil entering the body in this manner may cause blood poisoning. Therefore, it is essential that all parts of the

body be kept out of the line of the fuel-oil spray when nozzles or injectors are being tested. Another factor which you must keep in mind, when maintaining an engine, is the possibility of a crankcase explosion. Do not remove the crankcase covers or other engine access covers, for maintenance work, until 15 minutes after the engine has been shut down, when it is known or suspected that there has been an explosion, a fire, or an overheated part in the crankcase. In the event that a bearing or other engine part has overheated, the admission of air into the crankcase may create an explosive mixture which is capable of producing a serious crankcase explosion. The precautions dealing with nozzle testers and crankcase explosions are only two of many which must be observed when you are doing maintenance work on an engine.

QUIZ

1. What is meant by progressive maintenance?
2. For most efficient operation, should the handle of a metal-edge strainer be turned (a) when fluid is passing through the strainer; or (b) when the strainer is not in use?
3. When a metal-edge strainer is being prepared for disassembly and cleaning, why should the oil drained from the strainer case be caught in a clean container and be retained?
4. For what type of trouble should a screen-type strainer be checked, after it has been cleaned?
5. Under what conditions may the element of a filter be washed?
6. To what extent may a zinc be allowed to deteriorate before replacement is made?
7. Give two methods by which heat exchangers may be cleaned and indicate the types of heat exchangers which may be cleaned by each method.
8. Give three reasons why the sea-water side of the element in an oil cooler may become clogged.
9. Name four approved tools which may be used in cleaning the element of a shell-and-tube cooler.
10. What are the two chemicals used to treat the water in the closed, cooling-water circuit of an internal combustion engine?
11. Why is it desirable to maintain the fresh water in the closed circuit of an engine cooling system in a slightly alkaline condition?
12. Name the three tests which are used to determine the condition of treated, engine-cooling water.
13. What is indicated when an alkalinity test of cooling water causes the test sample to turn yellow?
14. What trouble will occur if the sodium-chromate concentration in treated, engine-cooling water drops below 900 ppm? Why?
15. To which of the concentrations in treated cooling water do the following limits apply? (a) Between 900 and 1100 ppm; (b) below 100 ppm; (c) pH 8-10.

CHAPTER 15

MAINTENANCE OF ENGINE PUMPS AND VALVES

As a Fireman, you have been introduced to many of the shipboard applications of pumps and valves. Reference has also been made earlier in this course to these items of equipment. (See chapters 10 and 11.) This chapter deals primarily with the routine maintenance of the pumps and valves which are commonly found in the various systems of internal combustion engines.

PUMPS

Pumps are essential for the operation of many shipboard auxiliary systems as well as for the operation of internal combustion engines. Pump failure may cause failure of the plant or system to which the pump is providing service. For this reason, you must have a knowledge of some of the operating difficulties which may be encountered; and know how to perform routine maintenance which will keep pumps in operation.

Before proceeding with this section, you should review the basic operating principles of pumps. These principles are discussed in *Fireman,* NavPers 10520–A. For additional information on pumps, you should consult BuShips *Manual,* chapter 47, and the manufacturer's instruction book which is usually furnished with each pump.

Engine Pump Applications

An engine installation requires a number of pumps. Some of these pumps deliver fuel to the injection system or the carburetor; others circulate oil through the lubri-

cating system; and still others circulate fresh water or sea water (or both) for engine cooling. In most cases, these engine pumps are attached to the engine and are driven by the engine crankshaft through gears, chains, or belts. However, some pumps are separate from the engine and are driven by electric motors.

Various types of centrifugal pumps, rotary pumps, and reciprocating pumps are used in engine installations. The types most commonly used in each of the systems—fuel, oil, water—are indicated in the following paragraphs.

CENTRIFUGAL PUMPS.—In most, large, modern engines, the pumps used to circulate fresh water or salt water (or both) in the engine cooling system are of the centrifugal type. Centrifugal pumps are NOT positive-displacement pumps; that is, they do not deliver a definite quantity of liquid on each rotation. In a centrifugal pump, the amount of liquid delivered is proportional to the speed of the impeller.

ROTARY PUMPS.—All rotary pumps have rotating parts which trap the liquid at the suction side of the pump and force it through the discharge outlet. Gears, vanes, lobes, and screws are commonly used as the rotating elements in rotary pumps. Rotary pumps are positive-displacement pumps; that is, a definite amount of liquid is delivered on each rotation. In most rotary pumps, the direction of flow of the pumped liquid is dependent upon the direction of rotation of the rotors. However, some rotary pumps used for fuel transfer and for engine lubrication are made so that the direction of flow remains unchanged even when the direction of rotation of the pump rotors is reversed.

The two types of rotary pumps most commonly used in engine installations are gear type and the vane type. GEAR pumps are used as fuel pumps, in most Diesel installations; as lubricating-oil pumps; and as sea-water circulating pumps for the cooling systems of small, high-speed engines and of some medium-sized engines. VANE pumps are used as fuel-transfer pumps in some Diesel engines and in some gasoline engines.

Since rotary pumps operate on the positive-displacement principle, some provision must be made for recirculation of the liquid, in the event that the amount of liquid being pumped is greater than required. Typically, a rotary pump used in an engine installation is fitted with a spring-loaded bypass valve which allows the liquid to be recirculated from the discharge side back to the suction side of the pump.

RECIPROCATING PUMPS.—Reciprocating pumps, like rotary pumps, are positive-displacement pumps. The two types of reciprocating pumps most commonly used in engine installations are the plunger type and the diaphragm type. PLUNGER-TYPE reciprocating pumps are used in the fuel systems of some, small, Diesel engines. In some plunger-type pumps, the plunger of the pump is a part of the injection pump. In other cases, the fuel booster pump is a separate unit, which is bolted to the side of the injection pump housing and is operated by a cam on the

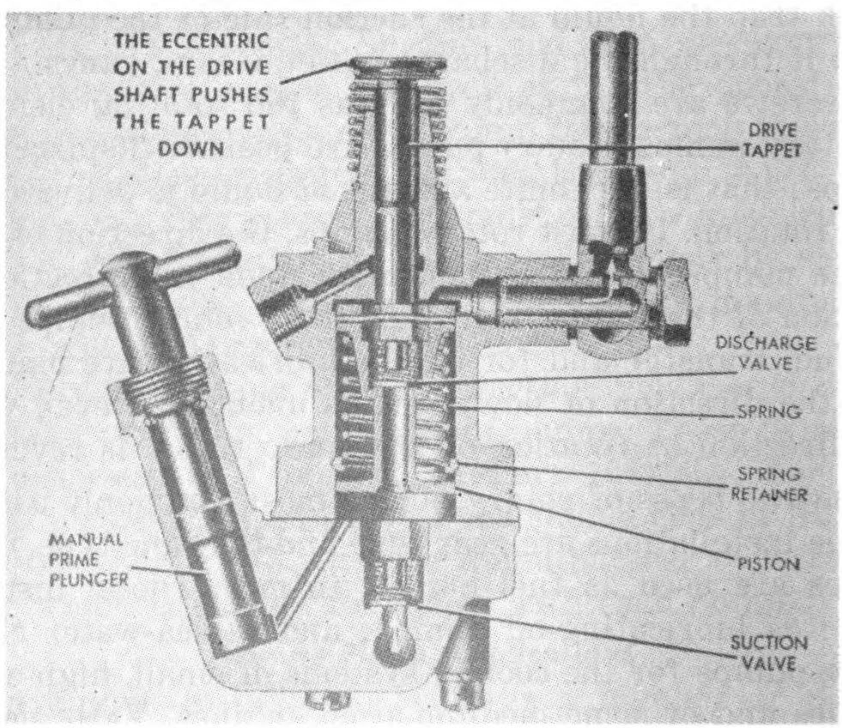


Figure 15—1.—Plunger-type fuel transfer pump (EX-CELL-O).

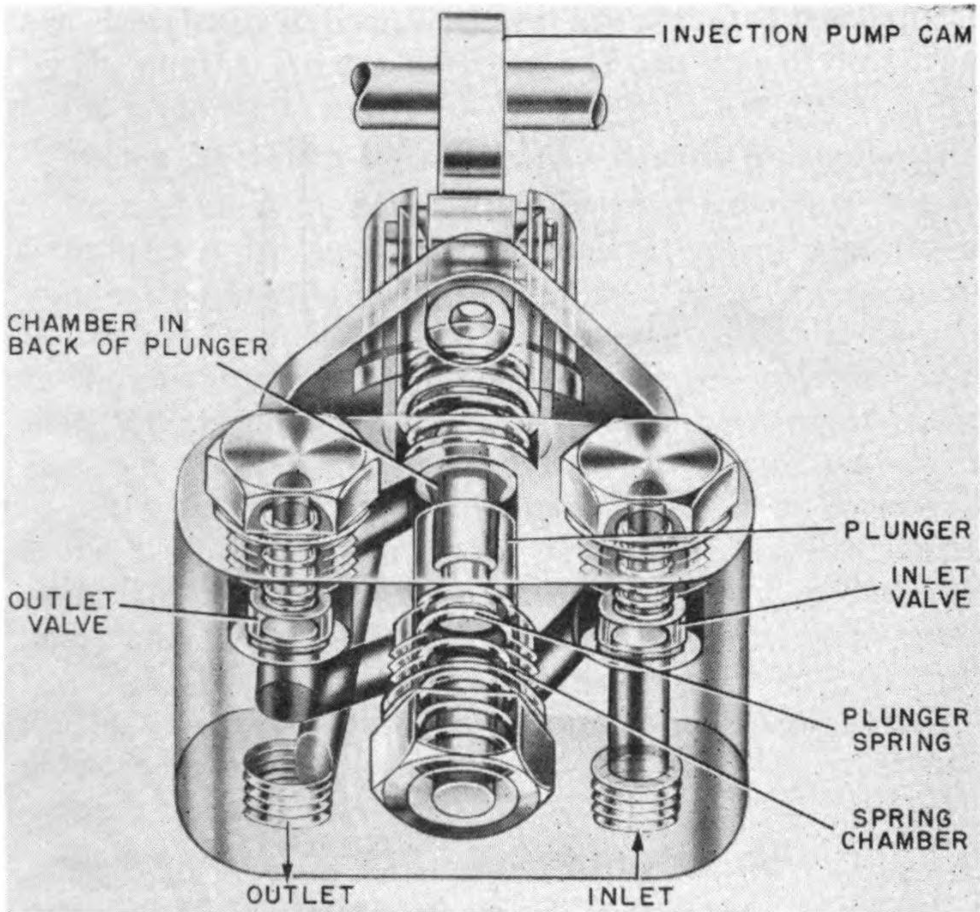


Figure 15–2.—Plunger-type fuel transfer pump (American Bosch).

injection-pump camshaft. Plunger pumps used for fuel transfer are of the variable stroke type. In this type of pump, the length of the stroke is automatically controlled by the pump discharge pressure. Thus, the capacity of the pump varies; but the discharge pressure is kept constant. Figures 15–1 and 15–2 show two different types of plunger pumps which are used for fuel transfer.

Reciprocating pumps of the plunger type are also used in some large engines, where special lubrication problems exist, to deliver oil to pistons and cylinder walls. These pumps are installed in addition to (and are independent of) the main lubrication system of the engine.

DIAPHRAGM-TYPE reciprocating pumps are used as fuel pumps on some gasoline engines. Some diaphragm pumps

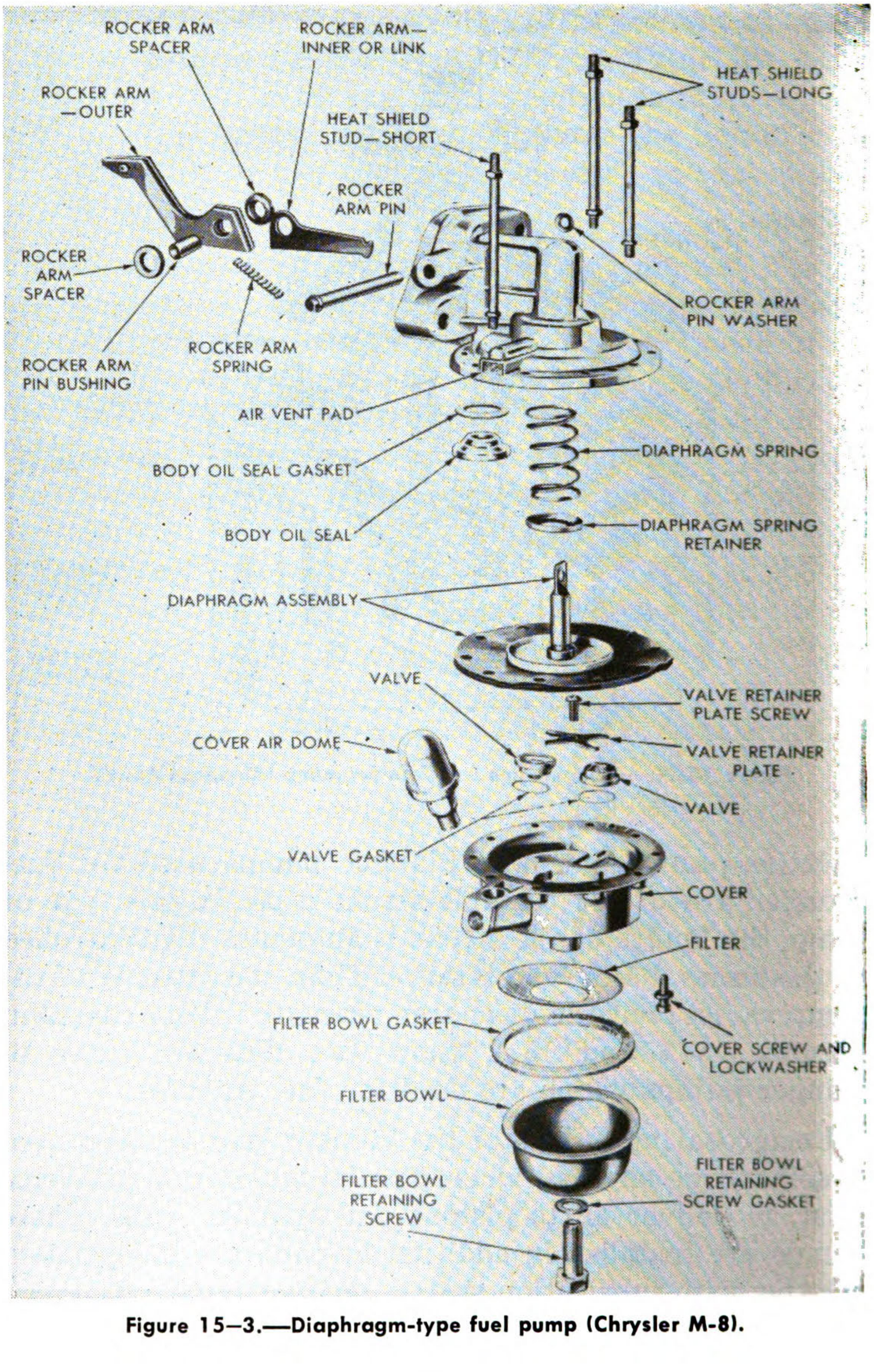


Figure 15–3.—Diaphragm-type fuel pump (Chrysler M-8).

are electrically driven, but most are actuated mechanically by the engine. An exploded view of one type of diaphragm pump is shown in figure 15–3.

Pump Operating Difficulties and Routine Maintenance

Pumps must be maintained in good condition to avoid a reduction in capacity. Insufficient capacity might endanger the engine in an emergency, when full speed and power are required. Particular attention should be given to the maintenance of pump clearances as specified in the instruction manual, and to the proper packing of pumps. Because of the number of different types of pumps and of different designs within each type, it is beyond the scope of this training course to provide detailed maintenance information on all pumps. The following discussion deals only with centrifugal pumps and rotary pumps of the gear type. For further details, and for specific information on any particular pump, you should study the manufacturer's instruction book furnished with each pump.

CENTRIFUGAL PUMPS.—The following information applies, in general, to most of the centrifugal water pumps used in connection with engines. A cross section of one type of centrifugal water pump used on some Diesel engine installations is shown in figure 15–4.

During the operation of a pump, precautionary measures must be taken to avoid conditions which would lead to insufficient pump discharge. This trouble becomes apparent when water and oil temperatures begin to rise. Water-pressure gages may also indicate whether or not water is being delivered. Always make sure that water is being circulated when the engine is started and that continuous circulation is maintained during engine operation. Extreme damage to cylinder block, liners, heads, and other costly engine parts may occur if the engine is not properly cooled.

There are a number of troubles which may cause insufficient pump discharge. Some of these troubles, the causes of them, and methods of preventing them; and

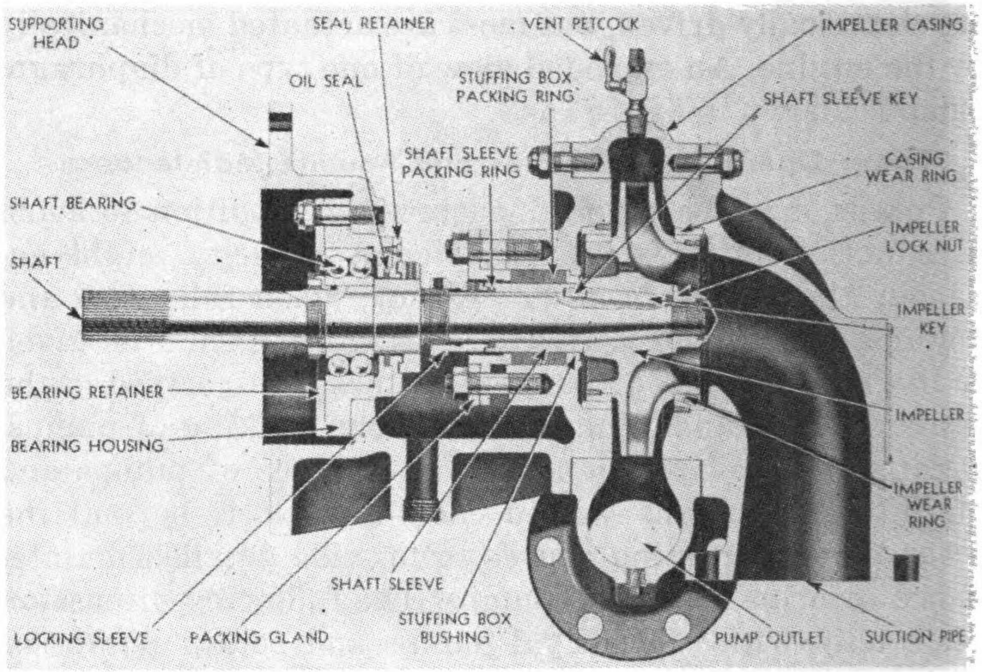


Figure 15–4.—Centrifugal water pump (GM 278A).

recommendations on maintenance are discussed in this section.

The capacity of a pump may be seriously reduced because of OBSTRUCTIONS ON THE SUCTION SIDE of the pump. Clogged strainers are most often the source of the trouble when the suction line becomes obstructed. If the water strainers are not properly installed or are not maintained in good condition, foreign material may clog the strainer and may even clog the passages of the pump impeller. Clogged suction lines will result in a reduction of pump capacity and will cause the temperature of the cooling water to rise. Solids which enter the pump may be trapped between the pump casing and the impeller, and cause breakage or scoring.

A clogged pump impeller must be cleaned. Care must be taken to avoid nicking or scratching the impeller, since nicks and scratches accelerate corrosion.

If suction strainers are properly maintained, much trouble can be avoided. Suction strainers are designed to screen out debris that would otherwise enter the water

pump. In performing their function, strainers will become clogged. It is important, therefore, that strainers be inspected and cleaned frequently. In some installations, inspection is facilitated by a plastic or glass strainer-housing. In other cases, it is necessary to release the hold-down clamps and remove the strainer basket for inspection.

Sea-water strainers are cleaned by dumping the debris from the basket, and cleaning the mesh with compressed air. The strainer housing should be cleaned also, so that the basket can be installed properly. It should never be necessary to force the strainer basket back into the housing.

A corroded or otherwise defective strainer basket or an improperly assembled strainer will allow foreign matter to pass into the circulating-water system. It is important, therefore, to inspect the basket for defects each time the strainer is cleaned; and to make sure the strainer is assembled correctly.

Another condition which must be avoided is OBSTRUCTIONS ON THE DISCHARGE SIDE of the pump. Centrifugal pumps are designed to operate against a specified maximum head, or resistance. If the head is too great, the capacity of the pump will be reduced. If the discharge piping or other water passages (such as those in the coolers) are clogged, the head on the pump will be increased and less water will be pumped. These passages must, therefore, be kept clean.

Lack of discharge from a pump may indicate that the shaft is broken. A BROKEN SHAFT may become apparent by the noise of breakage, a rise in cooling-water temperature, or the loss of discharge pressure. Broken shafts are generally the result of excessive vibration or damaged bearings. Excessive tightening of the shaft packing-gland may also lead to shaft breakage.

Vibration of the pump may set up extreme stresses in the pump shaft. When they are sufficiently severe, these stresses will cause fracture of the shaft. Vibration may

be due to breakage of the impeller, partial clogging of the impeller, or other conditions causing unbalance of the impeller. An alert watch should be kept for signs of unusual vibration of any part of the engine.

If the bearings are allowed to corrode, or if they seize from other causes, the increased load on the pump shaft may be sufficient to cause fracture. The bearings should be inspected carefully for indications of sea water entering the bearings. The location of the salt-water leak should be determined and the situation should be corrected. Worn or seized bearings must be replaced.

Shaft bearings which are in poor condition may be responsible for rapid wear of the packing or other shaft-seals. When a bearing is worn excessively, the resultant lowering of the shaft causes rapid wear of the packing. In such cases replacement of the packing will be ineffective in stopping leaks. Excessive end play of the rotor shaft may also be caused by poor condition of the bearings.

Bearings should be inspected carefully for signs of pitting or scoring. This is especially important in regard to ball bearings and roller bearings. Overheating of bearings of these types may be caused by overlubrication.

One of the most prevalent causes of bearing trouble in sea-water pumps is the presence of sea water in the bearings. Sea water quickly ruins bearings by corroding them. Sea water may enter bearings by leaking past the shaft seals. In some sea-water pumps, water leaks from the stuffing box into the "cradle" below the stuffing box. Unless the cradle drain hole is unobstructed, water may fill this cradle and leak into the bearing housing. This drain hole must, therefore, be inspected frequently, and kept clean and unobstructed.

The bearing housings should be inspected for signs of salt-water entry, when the pump is being repacked. A damaged bearing must be replaced, in accordance with the instruction manual. The bearings must not be overlubricated.

Most centrifugal water-pumps are equipped with ad-

justable sealing devices known as stuffing boxes. Rings of packing are fitted around the shaft, inside the stuffing box; when the nuts or screws on the stuffing-box gland are tightened, the packing is squeezed against the shaft and against the casing. The packing should never be overtightened. If the packing is squeezed too tightly, it will tend to bind against the shaft and cause overheating, excessive power consumption, undue stresses in the shaft, scoring of the shaft, and possibly breakage. When more than one nut or screw is provided, care should be taken to tighten all of them evenly. They should be tightened only to the point where a small amount of leakage is still present. In no case should the adjusting nuts be tightened more than just snug. In most cases, a drip rate of about six to ten drops per minute is proper.

Some pumps are equipped with sealing devices that require no adjustments and that do not need to leak to prevent scoring of the shaft. The applicable instruction manual should be consulted for the proper method of renewing these nonadjustable seals.

When PACKING BECOMES DAMAGED or causes scoring of the pump shaft, new packing must be installed. The procedures for repacking stuffing boxes will differ slightly, depending on the design of the pump. The procedure for repacking the pump illustrated in figure 15–4 is as follows:

1. Remove the packing gland and the packing. (Refer to fig. 15–4.)

2. Carefully clean the stuffing box. Be sure it is free of dirt and particles of old packing.

3. Inspect the shaft (or the shaft sleeve, if installed). If scoring is apparent, make replacement according to manufacturer's instructions.

4. Select packing of the correct size (cross section) and of the correct material.

5. Dip each ring of packing in oil; put one ring at a time in the stuffing box, pushing each ring well into place. The joints of succeeding rings must be staggered.

6. After the last ring of packing has been installed, replace the packing gland. Tighten the gland nuts evenly until they are snug; then loosen the gland nuts and retighten them to finger tightness. After the pump has been run, it may be necessary to readjust the packing gland. When the gland is being adjusted, the gland nuts should be tightened evenly, in steps, while the pump is in operation. Always allow a slight leakage, to lubricate the packing.

The inability of a pump to deliver water at the rated capacity and pressure may be caused by excessive clearance between the impeller hub and the casing. Wear of either the impeller hub surface or the casing area around the hub increases the clearance and allows liquid from the discharge of the pump to leak back to the suction side.

Most centrifugal pumps are provided with renewable rings, called wearing rings, for both the impeller hub and the casing area around the hub (See fig. 15–4.) Thus, when the surfaces between the impeller and the casing wear to the point where the clearance becomes excessive, the improper clearance can be corrected by removing the WORN WEARING RINGS and installing new ones. When clearance becomes excessive in pumps not provided with wearing rings, it is necessary to renew the impeller and build up the casing in order to restore the capacity of the pump.

In a centrifugal pump, the designed clearance between the impeller hub and the casing is very small; therefore, the impeller and casing surfaces in this area are always subject to a certain amount of wear. However, the observation of two operating precautions will help to minimize wear and to prevent the necessity for early replacement of parts. These precautions are: (1) do not allow the pump to run dry; and (2) avoid pumping fluids which contain abrasive material.

If the pump is allowed to run dry, air friction within the pump may cause a slight increase in temperature. The heat may expand the impeller sufficiently to cause the impeller ring to rub against the casing ring. Once the rub-

bing occurs, additional heat will be created; the resultant additional expansion of the impeller causes more severe rubbing, which may even cause the impeller to seize the casing.

The sea-water strainer must be kept in good condition to prevent the introduction of sand or other abrasive material into the cooling system. Many pumps introduce water under pressure into the packing gland, to aid in sealing. If the water being pumped has not been thoroughly strained to remove abrasive particles, these particles will score the shaft and quickly damage the packing.

Pump troubles may result from CORROSION OF PUMP PARTS. Pitting of the shaft, bearings, impeller, etc., may be due to corrosion. Corrosion of pump parts may be accelerated if the zincs are in poor condition. The zincs must be maintained properly in order to protect the cooling system. (See chapters 10 and 14.)

GEAR PUMPS.—The causes of trouble in gear-type pumps are, for the most part, quite similar to those described in the discussion of centrifugal pumps. In the following paragraphs, we will take up some of the difficulties most commonly encountered in gear-type pumps used for fuel transfer, lubricating-oil service, and cooling-water service.

Worn packing, with resultant leakage at the shaft gland, is a very common cause of trouble in gear pumps. Excessive wear of the packing is most likely to be caused by overtightened packing glands, scored pump shafts, worn bushings, or worn bearings. The packing gland should be tightened only enough to prevent steady leakage; a slight amount of liquid should be allowed to leak off between the packing and the shaft, to ensure lubrication of the packing. Worn bearings and worn bushings should be renewed when necessary.

Insufficient spring tension on the bypass valve is sometimes a cause of low pressure in the discharge line. This trouble may be corrected by tightening the adjusting screw. Before making this adjustment, however, inspect

the spring to be sure that it is not cracked or deformed; also, check the other parts of the bypass valve to be sure that they are in good condition. Be sure that the valve seats properly, and that no moving parts bind or stick.

When the gears in a gear-type pump become worn, the excessive clearances allow the pumped liquid to leak from the discharge side to the suction side, thus causing a reduction in discharge pressure. Gears should be renewed when the clearances become excessive. Worn bushings and worn bearings should be replaced promptly in order to prevent off-center rotation of the gears, with consequent damage to gears and casing.

Obstructions on either the suction side or the discharge side of the pump will cause faulty operation. Obstructions in suction or discharge lines may usually be cleared by passing a wire through the lines. All piping should be maintained in good condition, and should be inspected frequently for kinks or dents. The suction piping should also be inspected for cracks which would allow the entrance of air.

Pump Lubrication

Efficient and trouble-free operation of a pump depends a great deal on proper lubrication of the bearings and packing. In many cases, pump failures are the direct result of improper or inadequate lubrication. The method and type of lubrication for a particular pump will depend upon the type of pump and the service for which the pump is used. For example, the bearings and packing of some pumps which are used to transfer fuel oil or lubricating oil are lubricated by the liquid being pumped. A slight seepage between the shaft and the bearing or between the shaft and the packing provides the necessary lubrication. In other cases, bearings are lubricated with grease through pressure fittings or grease cups. Splash lubrication is also used in some cases. Oil supplied by the engine oil system provides lubrication of pump bearings, in some cases, through grooves and drilled passages. The bearings

of some pumps are of the "sealed," or "shielded," type. Bearings of this type are filled with lubricant when they are assembled; they require no further lubrication.

VALVES

In the various systems of an internal combustion engine, valves of many types are used to regulate the quantity of liquid flowing to the various components of the systems. All valves used in engine systems may be grouped, however, in two general classifications: manually operated valves; and automatic valves.

Manually operated valves include all valves that are adjusted by hand. Automatic valves include check valves, thermostatic valves, and pressure-regulating valves. Most of these valves have been introduced and illustrated in *Fireman,* NavPers 10520–A. Thermostatic valves have been discussed in chapter 13 of this training course. The valves considered in this chapter are primarily of the manual type; a brief discussion of some automatic valves is included. Some of the troubles which may be encountered with valves, and information on general maintenance is presented in this section.

Globe Valves

The repair of globe valves (other than routine renewing of packing) is generally limited to refinishing the seat and disk surfaces. When this work is being done, there are certain precautions that should be observed.

When refinishing the valve face and seat, no more material should be removed than is necessary. Valves that do not have replaceable valve seats can be refinished only a limited number of times.

Before you do any repair to the seat and disk of a globe valve, check the valve disk to make certain it is secured rigidly to and is square on the valve stem. Also, check to be sure that the stem is straight. If the stem is not straight, the valve disk can not seat properly. The valve seat and valve disk should be carefully inspected for evidence of wear, for cuts on the seating area, and for improper fit of the disk to the seat. If the disk and the

seat appear to be in good condition, they should be spotted-in to find out whether they actually are in good condition.

SPOTTING-IN VALVES.—The method used to determine visually whether or not the seat and the disk make good contact with each other is called spotting-in. To spot-in a valve seat, first apply a thin coating of Prussian blue evenly over the entire machined face surface of the disk. Then, insert the disk into the valve; and rotate it a quarter turn, using a light downward pressure. The Prussian blue will adhere to the valve seat at those points where the disk makes contact. Figure 15–5 shows what a correct seat looks like when it is spotted-in; it also shows what various kinds of imperfect seats look like.

After you have noted the condition of the seat surface, wipe all the Prussian blue off the disk face surface. Apply a thin, even coat of Prussian blue to the contact face of the seat, and again place the disk on the valve seat and rotate the disk a quarter of a turn. Examine the resulting blue ring on the valve disk. The ring should be unbroken

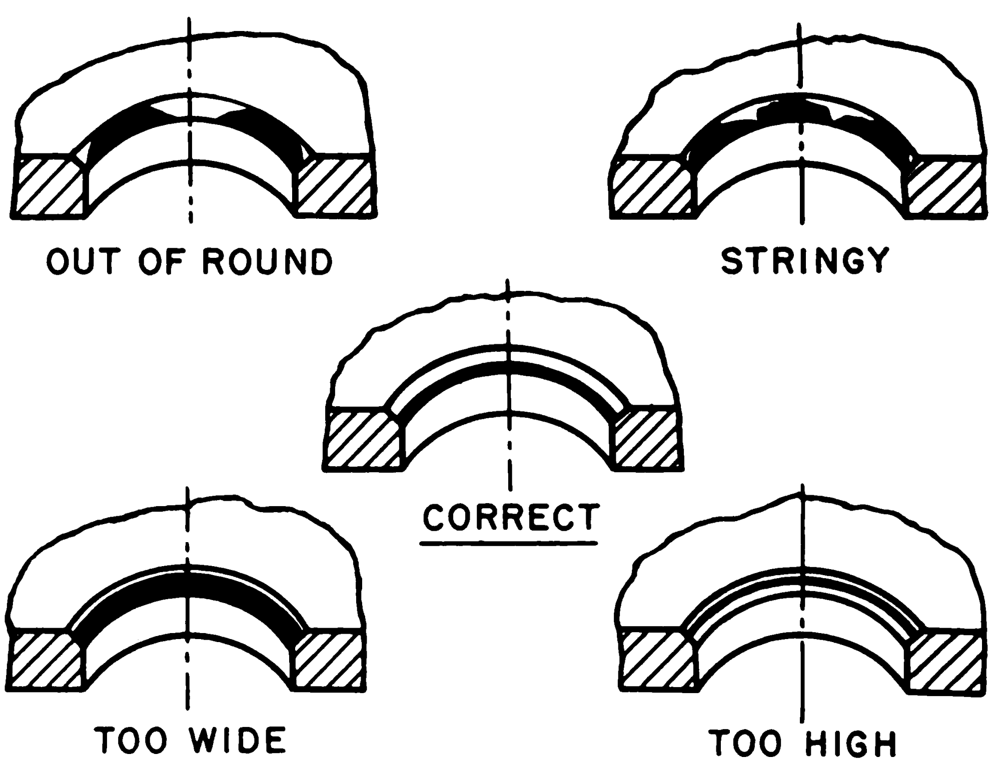


Figure 15–5.—Examples of spotted-in valve seats.

and of uniform width. If the blue ring is broken in any way, the disk is not making a proper fit.

GRINDING-IN VALVES.—The process used to remove small irregularities from the contact surfaces of the seat and the disk of a valve is called grinding-in.

To grind-in a valve, first apply a small amount of grinding compound to the face of the disk. Then insert the disk into the valve and rotate the disk back and forth about a quarter of a turn; shift the disk-seat relation from time to time so that the disk will be moved gradually, in increments, through several rotations. During the grinding process, the grinding compound will gradually be displaced from between the seat and disk surfaces; therefore, it is necessary to stop every minute or so to replenish the compound. When you do this, you should wipe both the seat and the disk clean before applying the new compound to the disk face.

When it appears that the irregularities have been removed, spot-in the disk to the seat, in the manner previously described.

Grinding is also used to follow up all machining work on valve seats or disks. When the valve seat and disk are first spotted-in after they have been machined, the seat contact will be very narrow and will be located close to the bore. Grinding-in, using finer and finer compounds as the work progresses, causes the seat contact to become broader. The contact area should be a perfect ring, covering approximately one-third of the seating surface.

Be careful that you do not overgrind a valve seat or disk. Overgrinding tends to produce a groove in the seating surface of the disk; it also tends to round off the straight, angular surface of the disk. Machining is the only process by which overgrinding can be corrected.

LAPPING VALVES.—When a valve seat contains irregularities that are slightly larger than can be satisfactorily removed by grinding-in, the irregularities can be removed by lapping. A cast-iron lapping tool (LAP), of exactly the same size and shape as the valve disk, is used

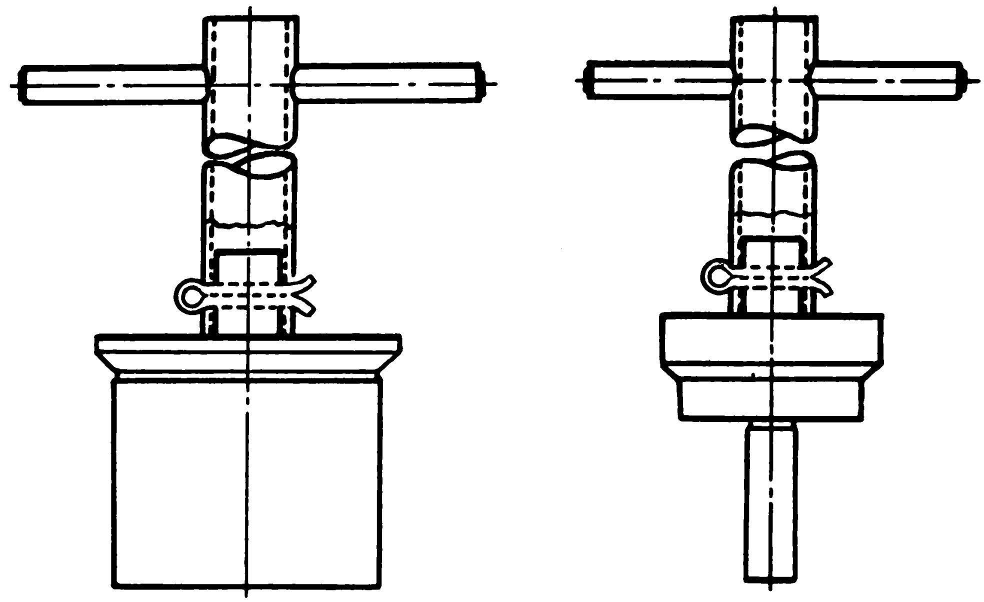


Figure 15–6.—Lapping tools.

to true the valve-seat surface. Two lapping tools are shown in figure 15–6.

The most important points to remember while using the lapping tool are:

1. Do not bear heavily on the handle of the lap.
2. Do not bear sideways on the handle of the lap.
3. Change the relationship between the lap and the valve seat so that the lap will gradually and slowly rotate around the entire seat circle.
4. Keep a check on the working surface of the lap. If a groove develops, have the lap refaced.
5. Always use clean compound for lapping.
6. Replace the compound often.
7. Spread the compound evenly and lightly.
8. Do not lap more than is necessary to produce a smooth, even seat.
9. Always use a fine grinding compound to finish the lapping job.
10. Upon completion of the lapping job, spot-in and grind-in the disk to the seat.

Only approved abrasive compounds should be used for reconditioning valve seats and disks. Compounds for lap-

ping and grinding valve disks and seats are supplied in four grades. A coarse-grade compound is used when extensive corrosion or deep cuts and scratches are found on the disks and seats. A compound of medium grade is used to follow up the coarse grade; it may also be used to start the reconditioning process on valves which are not too severely damaged. A fine-grade compound should be used when the reconditioning process nears completion. A microscopic-fine grade is used for finish lapping, and for all grinding-in.

REPACKING OF VALVE STUFFING BOXES.—If the stem of a globe valve is in good condition, stuffing-box leaks can usually be stopped by setting up on the gland. If this does not stop the leakage, repack the stuffing box. The gland must not be set up on or packed so tightly that the stem binds. If the leak persists, a bent or scored valve stem may be the cause of the trouble.

Coils (string) and rings are the common forms of packing used in valves. The form to be used in repacking a particular valve will be determined, in part, by the size of the packing required. In general, rings are used in valves that require packing larger than 1/4-inch. When a smaller size is required, string packing is generally used.

When a valve stuffing box is being repacked, successive turns of the packing material are placed around the valve stem. When string packing is used, it is coiled around the valve stem. The ends are beveled off to make a smooth seating for the bottom of the gland; the gland is then put on, and set up by the bonnet nut or the gland bolts and nuts. To prevent the string packing from folding back when the gland is tightened, the packing should be wound in the direction in which the gland nut is to be turned. Where successive rings are used, the different rings should break joints.

Gate Valves

The manner in which a gate valve is used has a great deal to do with the service life of the valve. Gate valves should always be used either wide open or fully closed.

They should not be used in a partially-opened position. When a gate valve is partly open, the gate is not held securely; therefore, it swings back and forth with the pulsation of the flow. As the gate swings, it strikes the valve body and the finished surfaces, nicking and scoring them. When these surfaces are imperfect, the valve gate cannot seat accurately and seal off the flow. A gate valve should never be installed in any position where a throttling or flow-regulating valve is required; for such service, a globe valve should be used.

Lapping is the best method for correcting gate-valve defects such as light pitting or scoring, and imperfect seat-contact. The lapping process is the same for gate valves as it is for globe valves, except that the lap is turned by a handle which extends through the end of the valve body. The lapping tool, without its handle, is inserted into the valve in such a manner that it covers one of the seat rings. Then, the handle is attached to the lap and the lapping is begun. The wedge gate can be lapped to a true surface, using the same lap that is used on the seat rings. CAUTION: Do NOT use the gate as a lap.

No more material should be removed than is necessary. It is possible to resurface a gate valve only a limited number of times. By removing too much material each time, the total number of times the surfaces can be renewed will be decreased, and the over-all life of the valve will thereby be shortened.

It is not advisable to attempt to repair a gate valve without removing it from the piping system. Removing the valve simplifies the repair job and gives more assurance that a good job will be performed.

Leakage around the stem of a gate valve is caused by troubles similar to those encountered in leaking globe valves. The procedure for stopping leakage around the valve stem is the same for both types of valves.

Plug-Cock Valves

Manually operated valves of the plug-cock type are sometimes used in engine cooling-system lines. A valve

of the plug type employs a rotating plug, which is drilled for the passage of the fluid. Rotation of the plug changes the position of the drilled passages with respect to the ports of the valve. In this manner, the rate (and, in three-way proportioning valves, the direction,) of flow of the coolant is adjusted.

A hard lubricant in stick form is used to effectively seal and lubricate the rotating plug. Proper lubrication ensures tightness, maximum life, and ease of operation. Improper lubrication may cause the valve to stick or to leak, and may cause excessive wear of the rotating plug. Excessive lubrication should be avoided, as it may cause grease to be deposited in the cooling-system components.

Instructions relative to the proper lubrication of plug-cock valves must be followed strictly, if valve trouble is to be avoided. Many times, it is necessary only to lubricate the valve to eliminate leakage or sticking of the plug. However, if the valve has not been properly lubricated for a long time, it may be necessary to replace valve parts that have been damaged by lack of lubricant.

Lubricate the valve by removing the lubricant setscrew and inserting a stick of lubricant. (The type of lubricant to be used is dependent upon the fluid that the valve is handling.) After the stick of lubricant is inserted, the lubricant is forced into the plug-cock valve by means of the lubricant setscrew until the lubricant is forced out around the neck or the stem of the valve. A check valve within the lubricant passage allows the plug-cock valve to be lubricated under pressure. When a plug-cock valve is being lubricated, the valve must either be wide open or completely closed. If this precaution is not taken, the lubricant will be forced into the water stream and will not lubricate the valve.

Check Valves

Check valves are used to prevent the back-flow of fluid in a line. A typical check valve is actuated by a light spring that seats the valve when the flow ceases.

Leaks are the principal trouble encountered with check valves. Leakage is caused by a pitted disk or valve seat. Such pitting usually results from abrasives becoming caught between the disk and the seat.

When a check valve requires maintenance because of pitting, the work required will depend upon the type disk in the valve. When a leaking check valve has a ball-type disk, it will be necessary to replace the ball and to grind the seat. When a defective valve has a flat or conical disk, it will usually be possible to repair the damaged surfaces by grinding the disk to its seat, with a fine grinding compound.

When installing or replacing check valves, it must be remembered that fluid will flow through them in only one direction. Be sure that they are installed correctly.

Pressure-Regulating Valves

Pressure-regulating valves are required in a lubricating-oil system to maintain an even lubricating-oil pressure as the engine speed changes. Since lubricating-oil pumps are of the positive-displacement type, it is essential that excess oil be afforded some means of escape; otherwise extremely high pressures in the lines and at the bearings will develop. Defective pressure-regulating valves are evidenced by low and erratic lubricating-oil pressures, which are most noticeable when the lubricating-oil temperature is high. There are many other factors, however, that will cause the same symptoms; these include a clogged filter or cooler, a worn oil pump, loose bearings, a low oil level, high oil temperatures, oil dilution, and oil leaks.

Most pressure-regulating valve failures are due to wear in the valves. However, a valve may fail to function properly because of a loose lock-nut, a scored seating surface, the binding of moving parts, or other defects.

If the adjusting-screw lock nut becomes loose, the adjusting screw will back off, decreasing the tension in the spring and the load on the valve. Scored and pitted valves and valve seats will cause poor pressure-control. When

the valve seat and the disk become badly pitted, the operation of the valve will often be irregular; sometimes it will maintain normal pressure, and at other times it will allow the pressure to fall below the required level. Should the assembly become gummed, due either to the oil or to foreign particles in the oil, the disk will stick in the open position, it will then offer no restriction to the amount of oil bypassed. This effect is more noticeable at the lower speeds. When a pressure-regulating valve fails to function properly, because of wear, the valve should be replaced.

QUIZ

1. In most, large, modern engines, what type of pump is used to circulate the water in the engine cooling system?
2. Why are positive-displacement pumps fitted with bypass valves?
3. Name two types of reciprocating pumps that are used in engine installations.
4. What is the most common cause of the failure of a sea-water circulating pump to take suction?
5. Give three symptoms which indicate that the shaft of a centrifugal water-pump may have broken.
6. When the stuffing box of a water pump is being repacked, should the joints of succeeding packing rings be lined up evenly, or should they be staggered?
7. Why is it necessary to allow a slight amount of leakage between a pump shaft and its packing?
8. What is likely to happen if a centrifugal pump is operated dry?
9. What should be done in order to determine visually if the seat and the disk of a globe valve are making satisfactory contact?
10. After a globe valve has been ground-in, how should you check the contact surfaces of the seat and the disk?
11. How can overgrinding of a valve seat or disk be corrected?
12. Under what circumstances is the lapping process used to refinish the seating surfaces of a globe valve?
13. What should be done to the seating surfaces of a globe valve after the lapping process has been completed?
14. How many grades of compound are needed to complete the lapping of a valve in which the seat is damaged extensively?
15. Give the steps which may be necessary if leakage occurs at the stuffing box of a globe valve in which the valve stem is in good condition.
16. When the stuffing box of a valve is being repacked with string-type packing, why should the packing be wound in the same direction as the gland nut is turned for tightening?
17. When a plug-cock valve in a cooling system is being lubricated, what precaution must be taken to prevent the lubricant from being forced into the water stream?

SECTION II

SHIPBOARD AUXILIARY MACHINERY AND EQUIPMENT

Air Compressors

Fire-Fighting Equipment

Hydraulic Equipment

Electrical Equipment

Refrigeration and Air Conditioning Systems

Distilling Units

CHAPTER 16

MISCELLANEOUS AUXILIARY EQUIPMENT

As an Engineman, you will be required to have an understanding of many types of auxiliary equipment installed aboard ship. This chapter contains information on some of the auxiliary equipment that you must know about: air compressors, fire-fighting equipment, hydraulic equipment, and electrical equipment. Information on some of the equipment used aboard ship for refrigeration and air conditioning and for distilling water is given in the following chapters of this course. For further information on shipboard auxiliary equipment discussed in this course, you should consult BuShips *Manual*, the appropriate manufacturers' instruction books, and other Navy training courses.

AIR COMPRESSORS

Three types of compressed air systems are used on board ship: low-pressure, medium-pressure, and high-pressure. Some ships have all three types; others have only low-pressure and high-pressure systems; and still others have only medium-pressure systems.

As an Engineman, you should know the principles of operation of the compressors used to supply air to each of the three types of air systems. In addition, you must be familiar with the procedure for lubricating compressors. Before you attempt to learn about air compressors, however, be sure that you understand the standard terminology used in the discussion of air compressors.

Definition of Terms

The following definitions apply chiefly to compressors of the reciprocating type; most air compressors used by the Navy are of this type.

COMPRESSING ELEMENT.—Includes the cylinder, the piston, and the air valves. A compressor may have more than one compressing element.

VERTICAL COMPRESSOR.—A compressor in which the compressing element or elements are in the vertical plane.

HORIZONTAL COMPRESSOR.—A compressor in which the compressing element or elements are in the horizontal plane.

ANGLE COMPRESSOR.—A multicylinder compressor in which the axes of the cylinders are at an angle to each other. Typical angle compressors in naval service are compressors of the vertical-V type and of the vertical-W (three cylinder radial) type.

DUPLEX COMPRESSOR.—A compressor which has two parallel sets of compressing elements driven by individual cranks on a common shaft.

SINGLE-ACTING COMPRESSOR.—A compressor in which compression takes place on only one stroke in each revolution of the crankshaft, as in a single-acting engine.

DOUBLE-ACTING COMPRESSOR.—A compressor in which compression takes place on both piston strokes in each revolution of the crankshaft, as in a double-acting engine.

COMPRESSION CYCLE.—The compression cycle of each stage consists of (1) a suction stroke, and (2) a compression stroke.

STAGE OF COMPRESSION.—One increase in pressure, occurring as the result of one act of compression (one suction stroke and one compression stroke).

SINGLE-STAGE COMPRESSOR.—A compressor in which compression of the air from initial pressure to final pressure is accomplished in one stage.

MULTISTAGE COMPRESSOR.—A compressor in which compression of the air from initial pressure to final pressure is accomplished in two or more stages, in sequence. The

air acquires a higher pressure and a smaller volume in each succeeding stage.

COMPRESSED-AIR RECEIVER (ACCUMULATOR).—A storage tank which serves to minimize pulsations in the discharge line of the compressor, and which supplies compressed air during intervals when the demand for air exceeds the capacity of the compressor. A receiver is installed in each space that houses air compressors.

COMPRESSION RATIO.—The ratio of the absolute discharge pressure to the absolute intake pressure, either for the compressor as a unit or for any one stage of the unit.

FREE AIR.—The air, at atmospheric pressure and temperature, in the space where the compressor is installed.

COMPRESSOR DISPLACEMENT.—The volume of air displaced in one minute by the first-stage piston or pistons on compression strokes. Compressor displacement is computed on the basis of the area of the piston and the length of stroke. Compressor displacement is expressed in cubic feet per minute.

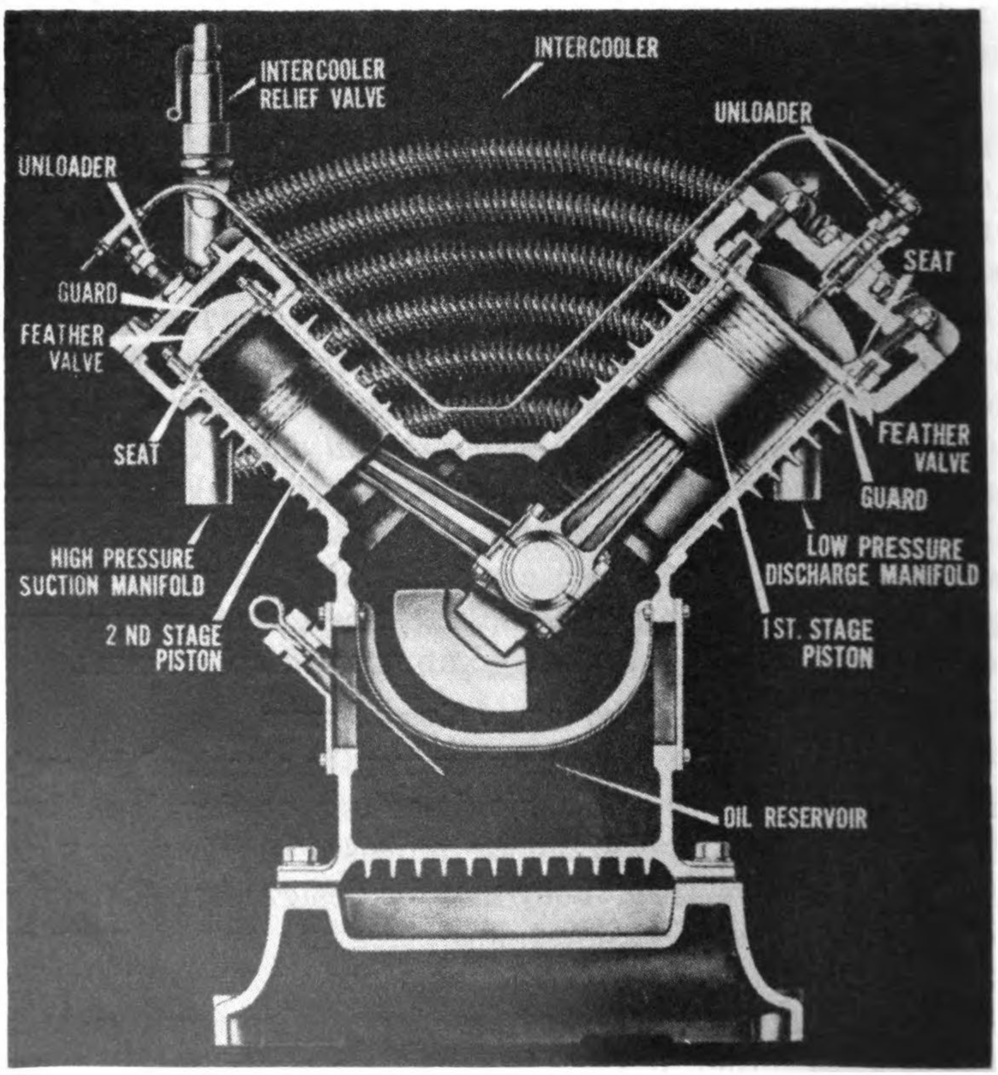
COMPRESSOR CAPACITY.—The quantity of air delivered or compressed. For low-pressure and medium-pressure compressors, capacity is expressed in cubic feet of free air per minute at intake temperature and intake pressure. For high-pressure compressors, capacity is expressed in cubic feet of compressed air per hour at final discharge pressure but at intake temperature. Actual compressor capacity is always less than compressor displacement.

Classification of Compressors

As we have seen, compressors may be classified in various ways. They may be single-acting or double-acting. They may be single-stage or multistage. They may be horizontal or vertical. They may be designed so that only one stage of compression takes place on one piston, or so that more than one stage takes place on one piston. In addition, compressors may be classified according to a number of other design features or operating characteristics.

In general, compressors are classified according to (a) the type of compressing elements; (b) the source of driving power; (c) the method by which the driving unit is connected to the compressor; and (d) the magnitude of the pressure developed. For example, the compressor shown in figure 16–1 may be described as a reciprocating, motor-driven, close-coupled, low-pressure air compressor.

COMPRESSING ELEMENTS.—As mentioned before, most of the compressors used by the Navy have RECIPROCATING compressing elements. In this type of compressor, the air is compressed in one or more cylinders in a process very



Form 16–1.—A reciprocating type air compressor.

much like the compression which takes place in the cylinder of an engine.

SOURCES OF POWER.—Compressors are driven by electric motors, internal combustion engines, steam turbines, or reciprocating steam engines. Most of the air compressors in naval service are driven by electric motors.

DRIVE CONNECTIONS.—The driving unit may be connected to the compressor by one of several methods. When the compressor and the driving unit are mounted on the same shaft, they are said to be CLOSE-COUPLED. Close coupling is often used for small-capacity compressors that are driven by electric motors. FLEXIBLE COUPLINGS are used to join the driving unit to the compressor in cases where the speed of the compressor and the speed of the driving unit (an electric motor or an internal combustion engine) can be the same. V-BELT drives are commonly used with small, low-pressure, motor-driven compressors, and with some medium-pressure and high-pressure compressors. In a few installations, a RIGID COUPLING is used between the compressor and the electric motor of a motor-driven compressor. In many cases, air compressors are driven through REDUCTION GEARS.

MAGNITUDE OF PRESSURE.—Compressors are commonly classified as low-pressure, medium-pressure, or high-pressure, according to the working pressure of the system to which they supply compressed air. As a rule, low-pressure compressors supply a working pressure of 100 psi; however, some low-pressure compressors are designed to supply compressed air at 125 psi. Medium-pressure compressors are designed to supply compressed air at working pressures within the range of 125 to 600 psi. High-pressure compressors supply air at a working pressure of 3000 psi.

Most LOW-PRESSURE air compressors are of the TWO-STAGE type with either a vertical-V (fig. 16–1) or a vertical-W (fig. 16–2) arrangement of the compressing elements. Two-stage, V-type, low-pressure compressors have one cylinder for the first (low-pressure) stage of compression; and one cylinder for the second (high-pressure) stage. W-type compressors have two cylinders

for the first stage of compression, and one cylinder for the second stage.

MEDIUM-PRESSURE air compressors are of the two-stage, vertical, duplex, single-acting type. Many medium-pressure compressors have differential pistons.

Modern HIGH-PRESSURE air compressors are of the vertical, duplex, single-acting type. High-pressure compressors are designed with either three or four stages of compression. Three-stage compressors are installed on vessels which require only a small supply of high-pressure air; four-stage compressors are used where a greater amount of high-pressure air is required. Three-stage compressors are usually driven by electric motors, to which they are joined by either close couplings or flexible couplings. Four-stage air compressors may be driven by steam turbines, through reduction gears; or by electric motors, either through reduction gears or through a direct connection.

Operating Cycle of Reciprocating Air Compressors

In spite of the wide variations that you will find in the design of modern reciprocating air compressors, it is well to remember that the basic compression cycle must always consist of two strokes: a suction stroke; and a compression stroke. Let's follow the cycle in a single-stage compressor.

SUCTION STROKE.—The suction stroke begins when the piston moves away from TDC. The air under pressure in the clearance space expands rapidly until the pressure falls below the pressure on the opposite side of the air-inlet valve. At this point, the difference in pressure causes the inlet valve to open: air is admitted to the cylinder. Air continues to flow into the cylinder until the piston reaches BDC.

COMPRESSION STROKE.—The compression stroke starts as the piston moves away from BDC; compression of the air begins. When the pressure in the cylinder equals the pressure on the opposite side of the air-inlet valve, the inlet valve closes. Air is increasingly compressed as the

piston moves toward TDC, until the pressure in the cylinder becomes great enough to force the discharge valve open, against the discharge-line pressure and the pressure of the valve springs. (The discharge valve opens a few degrees before TDC.) During the balance of the compression stroke, the air which has been compressed in the cylinder is discharged, at almost constant pressure, through the open discharge valve.

The basic compression cycle just described is clear enough when you consider a single-stage, single-acting compressor; but it may be more difficult to understand when you are considering a more complicated machine. Remember that the basic compression cycle will be repeated a number of times in double-acting compressors and in multistage compressors.

In a double-acting compressor, each stroke of the piston is a suction stroke in relation to one end of the cylinder and a compression stroke in relation to the other end of the cylinder. In a double-acting compressor, therefore, TWO basic compression cycles are always in process when the compressor is operating; but each cycle, considered separately, is simply one suction stroke and one compression stroke.

In multistage compressors, the basic compression cycle must occur at least once for each stage of compression. If the compressor is designed with two compressing elements for the first (low-pressure) stage, two compression cycles will be in process in the first stage at the same time. If the compressor is designed so that two stages of compression occur at the same time in one compressing element, the two basic compression cycles (one for each stage) will occur at the same time.

Compressing Element

The compressing element of a reciprocating air compressor consists of the air valves, the cylinder, and the piston.

AIR VALVES.—The valves of modern compressors (except for some high-pressure compressors aboard sub-

marines) are of the automatic type. The opening and closing of these valves is caused solely by the difference between (1) the pressure of the air within the cylinder, and (2) the pressure of the external air on the intake valve or the pressure of the air in the line on the discharge valve. The air valves used in air compressors differ considerably from the cam-actuated valves of an engine. On most compressors, a thin-plate, low-lift type of valve is used.

CYLINDERS AND PISTONS.—Various designs of cylinders and pistons are used, depending primarily upon the number of stages of compression which take place within a cylinder. Some common types of air cylinders and pistons are shown in figure 16–2. The arrangements shown in *A* are common to low-pressure and medium-pressure compressors; the arrangements shown in *B* are typical of three-stage and four-stage high-pressure compressors.

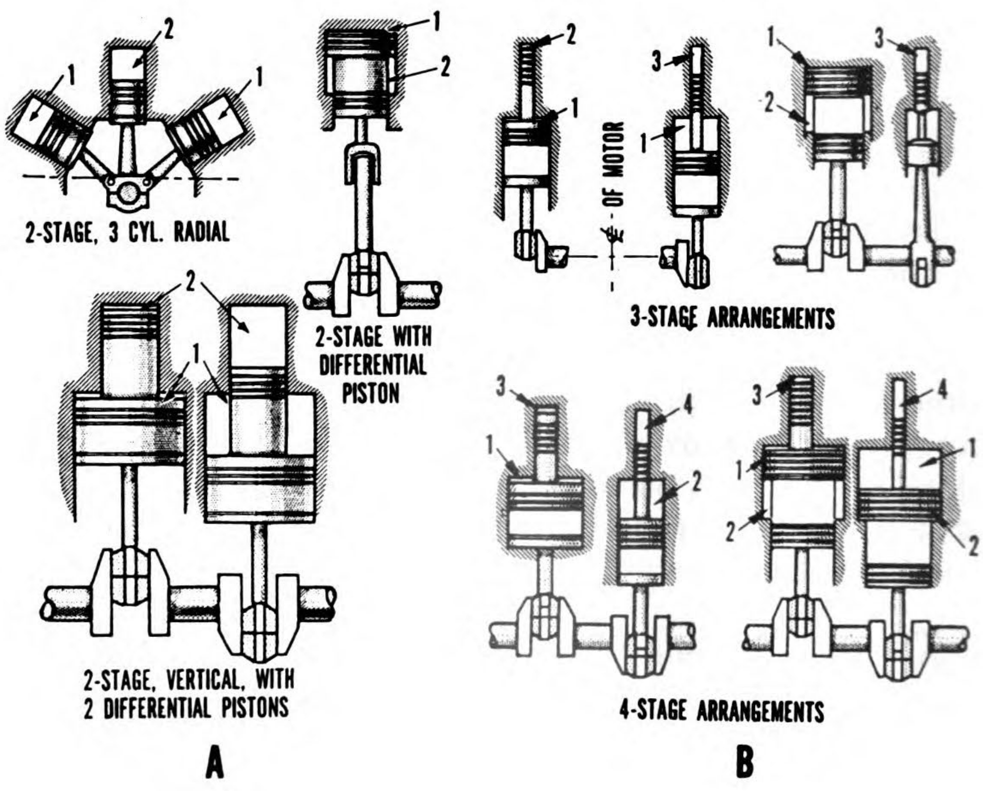


Figure 16–2.—Compression stage arrangements of air compressors.

The pistons used in reciprocating air compressors may be TRUNK PISTONS, DIFFERENTIAL PISTONS, or DOUBLE-ACTING PISTONS. Pistons of the trunk and differential types are most common. Trunk pistons and double-acting pistons are similar to the pistons used in internal combustion engines.

A differential piston is a modified trunk piston, which has two or more diameters. The piston is fitted into a special cylinder in such a way that two or more stages of compression are served by one piston. (See fig. 16–2.) When a differential piston has only two different diameters, the compression for one stage takes place over the piston crown; compression for the other stage takes place in the annular space between the large diameter and the small diameter of the piston.

Compressor Lubrication

For the purpose of this discussion, the lubrication of an air compressor is divided into two parts: cylinder lubrication, and running-gear lubrication.

CYLINDER LUBRICATION.—Lubrication of air-compressor cylinders is generally accomplished by means of a mechanical force-feed lubricator, which is driven from a reciprocating or a rotary part of the compressor. Oil is fed from the lubricator, by a separate feed line, to each cylinder. A check valve is installed at the end of each feed line to keep the compressed air from forcing the oil back into the lubricator. Each feed line is equipped with a sight-feed glass. Lubrication begins automatically as the compressor starts up. The amount of oil that must be fed to the cylinders depends upon the cylinder diameter, the cylinder-wall temperature, and the viscosity of the oil. The rate of feed for a particular compressor should be obtained from the applicable manufacturer's manual.

On small low-pressure and medium-pressure compressors the cylinders are lubricated by the splash method, from dippers on the ends of the connecting rods, instead of by a mechanical lubricator.

RUNNING-GEAR LUBRICATION.—Lubrication of the run-

ning gear of a modern compressor is accomplished by an oil pump, which is attached to the compressor and is driven from the compressor shaft. This pump (usually of the gear type) draws oil from the reservoir (fig. 16–1) in the compressor base; and delivers it, through a filter, to an oil cooler (fig. 16–3). From the cooler, the oil is distributed to the top of each main bearing, to spray nozzles for reduction gears, and to outboard bearings. The crankshaft is drilled so that oil fed to the main bearings is picked up at the main-bearing journals and carried to the crank-pin journals. The connecting rods contain passages which conduct lubricating oil from the crank-pin bearings up to the wrist-pin bushings. As oil leaks out from the various bearings, it drips back to the reservoir (in the base of the compressor) and is recirculated. Oil from the outboard bearings is carried back to the base by the drain lines.

The discharge pressure of lubricating-oil pumps varies with different pump designs. A relief valve, fitted to each pump, functions when the discharge pressure exceeds the pressure for which the valve is set. When the relief valve functions, excess oil is returned to the reservoir.

The proper lubrication of an air compressor may be the responsibility of the EN3. The height of oil in the reservoir of a compressor must be kept at the normal level at all times. The crankcase oil should be changed periodically. Kerosene or gasoline should never be used to clean or to flush out the compressor crankcase. Oil that has been removed may be purified and used again. Before the crankcase is refilled with fresh oil, the oil cooler and the oil filter should be cleaned. On recent designs of compressors, the oil filter is generally of the disk type. (See chapter 10.)

The oil pump requires very little attention. If sufficient pressure cannot be maintained in the lubricating system after the compressor has been in service for some time, the pump should be disassembled and checked for excess wear. Parts which show excessive wear must be replaced.

Erratic readings on the lubricating-oil pressure gages indicate that the pump is not receiving an adequate supply of oil. Pressure in the lubricating-oil system may be adjusted by means of a bypass relief valve. The pressure on this valve should be set in accordance with the recommendations given in the manufacturer's instruction book.

Compressor Cooling

All high-pressure and medium-pressure compressors are cooled by salt water supplied from the ship's fire, flushing, or cooling-water service mains. Cooling water is generally available to each unit from at least two sources. Compressors located outside the larger machinery spaces are generally equipped with an attached circulating-water pump as a standby source of cooling water. Small low-pressure compressors are aircooled by a fan mounted on, or driven from the compressor shaft.

Not all cooling-water systems have identical paths of water flow. In most cases, however, the path of the cooling water in a compressor cooling system is: first, through the intercoolers and the aftercooler; and lastly, through the cylinder heads and jackets. The path of water through the cooling-water system of a multistage compressor is illustrated in figure 16–3.

OIL COOLERS.—Oil coolers used in the cooling systems of compressors may be of the coil type, the tube-and-shell type, or a variety of commercial types. External oil coolers are generally used; some naval compressors, however, are fitted with a base-type oil cooler, in which cooling water is circulated through a coil in the oil reservoir. The tubes, coils, and cores of oil coolers are made of a copper-nickel alloy; the shell and the tube sheets are of bronze composition. On all late model compressors, the cooling-water system is provided with valves which are so arranged that the quantity of cooling water passing through the oil cooler may be regulated without disturbing the quantity of water going through the rest of the system. Thus, the oil temperature may be regulated without affecting the temperature in other parts of the system.

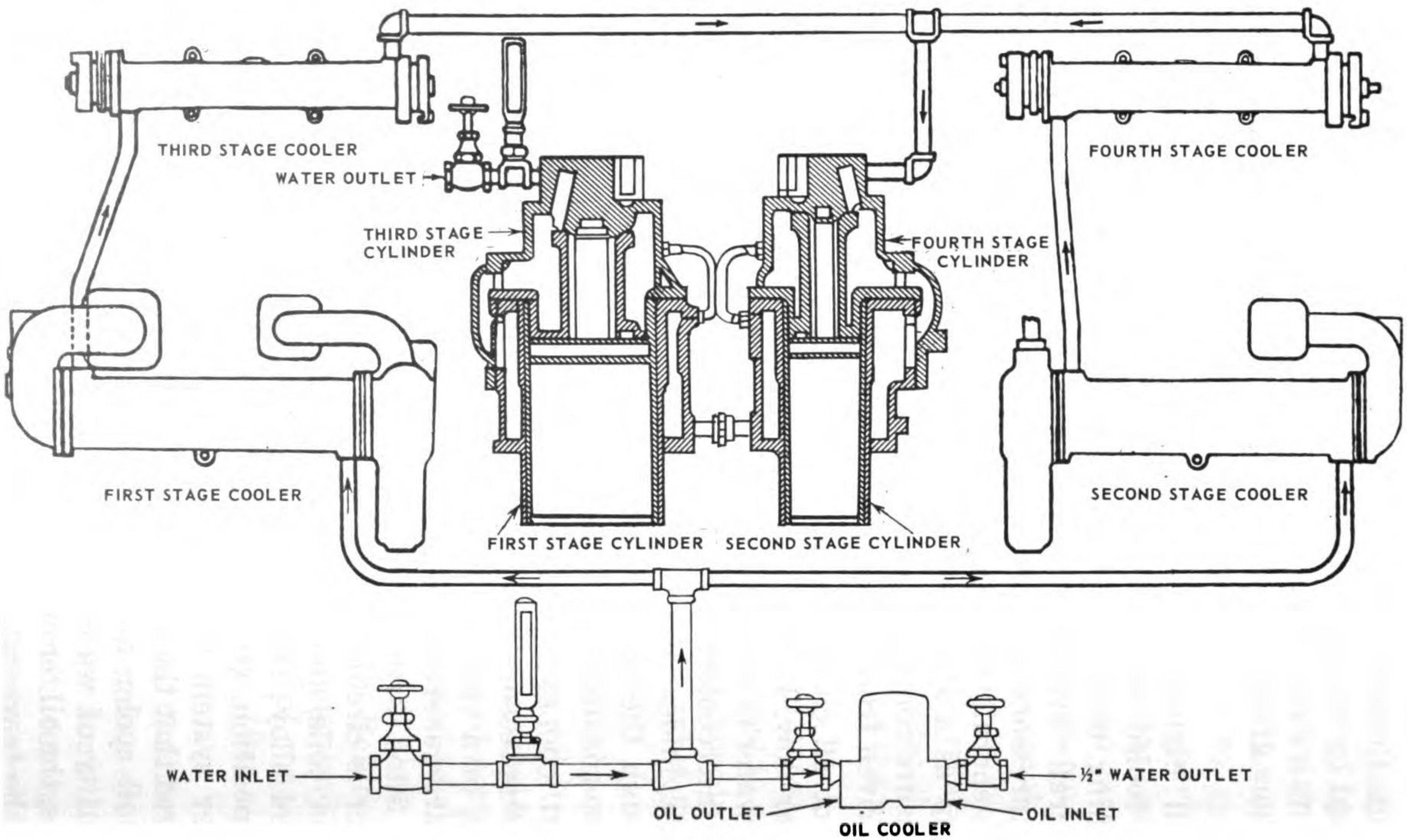


Figure 16—3.—Cooling-water system of a multistage compressor.

INTERCOOLERS AND AFTERCOOLERS.—The heat generated in a compressor during the stages of compression must be removed before the compressed air enters the air mains. This cooling causes any moisture in the air to condense; the condensate is then drained off. If the moisture condensed after the air had entered the air receiver or the air mains, serious trouble might occur when the compressed air was put to use. The removal of heat from the compressed air is also required for economical compression. If the air is not cooled after each stage, the air entering the next stage will be at a higher pressure than if the air had been cooled; the amount of work required to compress the uncooled air to the desired pressure will then be greater than if the air had been cooled.

The air is cooled between stages of compression by INTERCOOLERS. The high-pressure air discharged from the final stage of compression is cooled by an AFTERCOOLER. Some intercoolers and aftercoolers are water-cooled; others are air-cooled. Intercoolers and aftercoolers are of the same general construction, except that aftercoolers are designed to withstand a higher pressure than intercoolers.

Water-cooled intercoolers and aftercoolers are often of the straight tube-and-shell type; where space permits, they may be of the coil type. In the shell-and-tube intercoolers of compressors which have a discharge pressure below 250 psi, the air flows either through the tubes or over and around them. In larger compressors, the air flows through the tubes of the coolers. Baffles are provided in tubular coolers to deflect the air or water in its course through the cooler. In coil-type coolers the air passes through the coil; the water flows around the outside. Suitable provision is made for the expansion of the tube nest.

An air-cooled intercooler or aftercooler may be of the radiator type; or it may consist of a bank of finned copper tubes, located in the path of a blast of air supplied by the COMPRESSOR FAN.

Each water-cooled intercooler and aftercooler is fitted with a RELIEF VALVE on the air side and one on the water side. Water relief valves are generally set at 5 psi in excess of the maximum water pressure which may be applied to the system (155 psi for most compressors). The air relief valves must be kept set in accordance with directions given in the manufacturer's instruction book.

All intercoolers and aftercoolers are also fitted with SEPARATORS on the discharge side. The separators collect the water formed by the condensation of moisture in the air, and some oil from the compressor cylinders which is carried over by the compressed air. The separators are of a variety of designs; the removal of liquid may be accomplished by centrifugal force, by impact, or by sudden changes in velocity of the air stream. DRAINS, generally of an automatic type, are provided on each separator for removing the water and oil.

WATER JACKETS.—The water jackets are cast integral with the cylinders. These jackets are fitted with handholes and covers so that the water spaces may be inspected and cleaned. JUMPERS are generally used to make water connections between the cylinders and heads. The use of jumpers prevents any possibility of leakage into the compression spaces. In some compressors, however, the water passes directly from the cylinder jacket to the head. With this latter type, extreme care must be taken to ensure that the joint between the cylinder and head is properly gasketed to prevent leakage, since any continued leakage into the cylinder would ruin both the cylinder liner and the piston rings.

Compressor Controls

An air compressor may be equipped with one or more safety and control devices such as an automatic temperature shutdown device, a start-stop control, and a constant-speed control. (In the case of some compressors, the last two types of controls are combined in an arrangement known as dual control.)

AUTOMATIC TEMPERATURE SHUTDOWN DEVICES.—Devices of this type are fitted on all recent designs of high-pressure and medium-pressure compressors. Automatic temperature shutdown devices function when the cooling-water temperature rises above a safe limit. The device stops the compressor, and prevents it from restarting automatically.

START-STOP CONTROL.—Control, or regulating, systems for naval compressors are mainly of the start-stop type, in which the compressor starts and stops automatically as the receiver pressure falls and rises (within predetermined limits). On electrically driven compressors, the receiver pressure operates against a pressure switch; the switch opens when the pressure upon it reaches a given limit, and closes when the pressure drops to a predetermined level.

CONSTANT-SPEED CONTROL.—This is a method of controlling the pressure in the air receiver by controlling the output of the compressor, without stopping or changing the speed of the unit. This type of control is used on compressors which are required to furnish a fairly constant supply of air; that is, compressors which operate under conditions where frequent stopping and starting of the compressor are inadvisable.

DUAL CONTROL.—When control is of the dual type, the compressor can be made to operate under either a start-stop or constant-speed control at the will of the operator. Dual control has advantages on ships where the air mains must be kept under continuous pressure for long periods of time. The constant-speed control is used when the air demand is continuous; the start-stop control is used when the air demand is light.

Methods of Unloading Compressors

Air-compressor unloading systems are installed for the purpose of removing all loads (except, of course, the friction loads) from compressors; they automatically remove the compression load from the compressor while the unit is starting, and they automatically apply the load after

the unit is up to operating speed. For units having start-stop control, the system of unloading is separate from the system of control. On compressors equipped with constant-speed control or dual control, however, the unloading and the control systems are combined.

The air load on a compressor may be removed by one or more of the following methods: (1) closing or throttling the compressor intake; (2) holding the intake valves off their seats; (3) relieving intercoolers to the atmosphere; (4) relieving the final discharge to the atmosphere by opening a bypass from the discharge to the intake; (5) opening up cylinder clearance pockets; and (6) using miscellaneous constant-speed unloading devices.

A detailed explanation of the methods of unloading a compressor cannot be given here; be sure to refer to the applicable manufacturer's instruction book for a description of the unloading devices fitted on any compressor with which you may be working.

A Three-Stage Air Compressor

Three-stage air compressors are installed on vessels which require only a small supply of high-pressure air. These compressors are driven by electric motors; the motors are either close-coupled or flexible-coupled to the compressor shaft. The air flow through one type of three-stage, single-acting, vertical-V, air-cooled, reciprocating air compressor is illustrated in figure 16–4.

In the compressor illustrated, free (atmospheric-pressure) air is drawn into the two first-stage (low-pressure) cylinders, through the air-intake filter and the air-inlet valves, as the two first-stage pistons move downward on the suction stroke. As the first-stage pistons are moved upward, by action of the crankshaft, the first stage of compression takes place. The compressed air is discharged from the low-pressure discharge valves, through the first-stage discharge line, into the first-stage intercooler. After being cooled, the air enters the second-stage cylinder. (See fig. 16–4.) In the second stage of compression, the air is further compressed to a predetermined

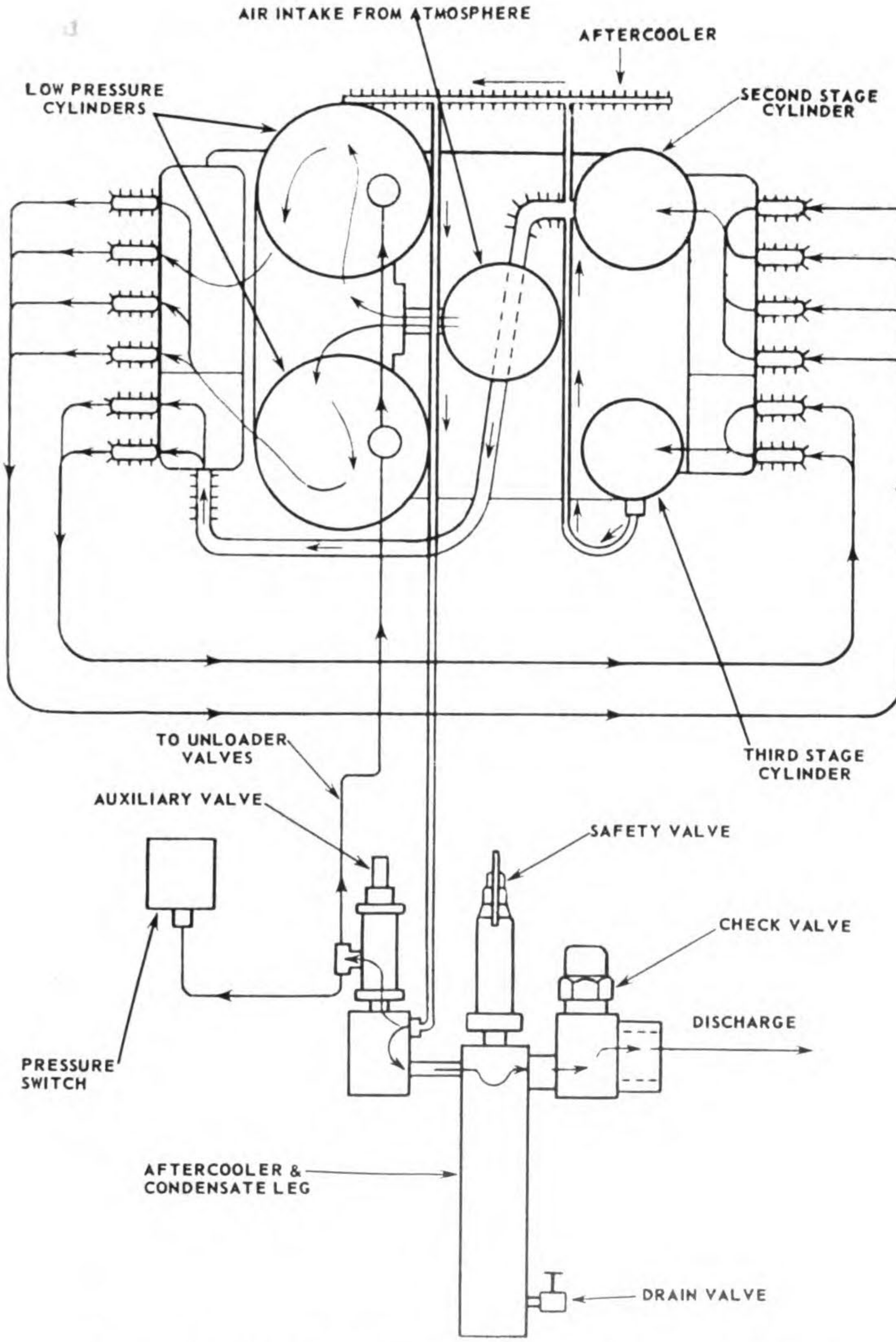


Figure 16—4.—Air-flow diagram for a three-stage air compressor.

pressure. The air is discharged from the second-stage cylinder into the second-stage intercooler, and is cooled again. The cooled air passes into the third-stage cylinder for the final stage of compression. When the final-discharge pressure is reached, the air leaves the third-stage cylinder, through the discharge piping, and enters the aftercooler (fig. 16–4). From the aftercooler, the compressed air is discharged into the air receiver.

Notes on Operating An Air Compressor

Before attempting to operate any air compressor, be sure that you are thoroughly familiar with the machine. Study the accompanying manufacturer's instruction manual and the instruction plates attached to the unit. There are so many varieties of compressors in use that any attempt to give you a set of general operating instructions which would apply to all of the types would be both futile and misleading. Understand and follow carefully the instructions posted for each machine. Don't depend upon your acquaintance with some other type of compressor.

Be sure you know every step required in the starting and securing procedures; what procedure is followed after an overhaul; when to check the oil level and the oil feed; when to drain the receivers and the cooler separators; how to interpret readings of pressure gages and thermometers; and the many other related matters which are important to efficient operation of the compressor.

Safety Precautions

There are a number of precautions which should be kept in mind when an air compressor is being operated and maintained. The instruction manual and posted instructions should be carefully checked and thoroughly understood before you attempt to operate a specific compressor. The following precautions apply, in general, to most air compressors.

OPERATION.—Remember that EXPLOSIONS within the compressor, the discharge line, or the receiver may be

caused by dust-laden intake air, oil vapor in the compressor or in the receiver, or abnormally high temperatures resulting from leaky or dirty valves.

1. Make every effort to have only clean, dry air at the compressor intake.

2. Do not clean compressor intake filters, cylinders, or air passages with benzine, kerosene, or other light oils; the fumes may collect and explode in the compressor or in the air receiver.

3. Use only the minimum amount and the specified grade of oil in lubricating air cylinders.

4. Secure compressor immediately if the temperature of the air discharged from any stage rises unduly or exceeds the recommended maximum operating temperature.

5. After starting the compressor, never leave it until you are certain that all control, unloading, and governing devices are working properly.

6. Avoid operating a compressor at excessive speeds.

7. Always maintain adequate cooling-water circulation, to prevent damage due to overheating.

8. Drain circulating water when the compressor is to remain idle for a long period in an exposed position in freezing weather.

MAINTENANCE.—Serious accidents may occur if precautions are not taken prior to working on a compressed-air system. Before working on or removing any part of a compressor, make sure that:

1. The system is not under pressure; check the pressure gages.

2. The compressor is actually secured and cannot be started.

3. All valves (including the control and unloading valves) between the compressor and the receiver are closed.

FIRE-FIGHTING EQUIPMENT

Information on the fire hazards which exist aboard ship and on much of the equipment used in fighting fires has been presented in *General Training Course for Petty*

Officers, NavPers 10055, and in *Fireman,* NavPers 10520–A. The information on fire-fighting equipment presented in this course deals primarily with engine-driven equipment.

Engine-Driven Fire Pumps

Fire pumps are usually of the horizontal, single-stage, centrifugal type, with double-suction impellers. Fire pumps are generally driven by either an electric motor or a steam turbine; emergency fire pumps, however, are usually driven by Diesel engines, and some portable pumps used in fire fighting are driven by gasoline engines.

CAPACITY AND LIMITATIONS OF ENGINE-DRIVEN PUMPS.—The gasoline engine-driven portable pumps used aboard ship are the handy billy and the P–500. The capacity and the limitations of each of these types of pumps are given in the Navy training courses mentioned earlier in this section. The capacities of pumps driven by Diesel engines may be from 100 to 250 gpm on small ships, and up to 2000 gpm on large vessels.

OPERATION OF FIRE AND FLUSHING PUMPS.—Instructions for the operation of all pumps cannot be covered in this course because of the great number of different makes, types, and designs in use in naval service. Manufacturers' instruction books are furnished with most engine-driven pumps. These instruction books contain detailed information concerning operation, maintenance, and repair; you should study them carefully before you attempt to operate the pump installation.

Operation of the P-500 Pump

Engine-driven P–500 pumps are furnished on practically every ship in the Navy. In the battle and disaster bills of a ship, Enginemen are commonly assigned to the P–500 pump teams as pump operators. The operating procedures for the P–500 pump are described in this section.

STARTING INSTRUCTIONS FOR THE P–500.—Before attempting to start the P–500, be sure that the suction-hose connections between the water and the pump are tight; and that the strainer (or eductor, when used) is securely

attached to the suction hose and completely submerged in the water. Use gaskets of the proper size at the suction-connection to the pump, and in all hose connections. Should the pump fail to take suction, or should the discharge at the nozzle show an uneven stream, it is probable that the air is leaking, through a poor connection, into the suction side of the pump. Careful attention must be given to the suction hose to see that the screen rests in clear water; if the screen rests in mud or gravel, these are likely to be drawn into the pump. Be sure to support the suction hose by a line, so that the weight of the hose will not be borne by the pump casing. Also make sure that the suction hose does not, at any point, rise above the level of the pump inlet; raising the hose above the inlet tends to form an air pocket, which interferes with proper priming. Do not run the pump in a confined space unless an exhaust hose is connected to carry toxic, engine-exhaust gases out of the space. With these inspections completed, proceed as follows:

1. Fill each of the two 7½-gallon fuel tanks with gasoline and Navy symbol 3065 (SAE 30) engine oil, mixed in the proportion of 1 pint of oil to 1 gallon of gasoline. Vigorous shaking is necessary in order to ensure a uniform mixture. The mixing may be done in the fuel tank itself, if the tank is empty; otherwise, a separate container should be used.

2. Mount the filled fuel tanks to the unit, securing them with the inboard spring-holddown clamps. When the tanks are mounted in their proper position, the vent valve on each tank is automatically opened.

3. Connect the unit's two fuel hoses to the bottom of the tanks.

4. Open the fuel-tank valves (wing nuts, one on each tank).

5. For one of the fuel tanks, turn the fuel valve on the control panel (fig. 16–5) from the OFF position to the ON position. See that the float-valve pin in the carburetor bowl rises, indicating that the bowl is full of fuel.

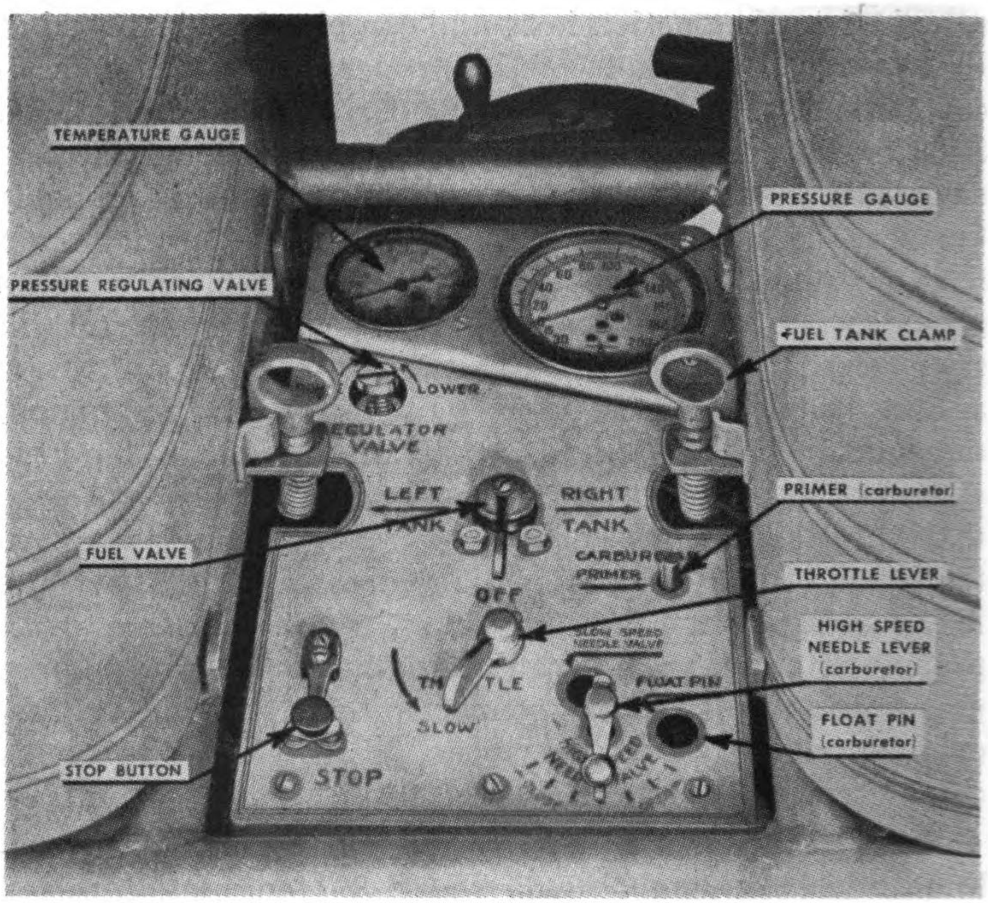


Figure 16–5.—Control panel of P–500 pump.

6. Close both Y-valves. (When the eductor is being used, the Y-valve which is connected to the pressure hose leading to the eductor should be open; the other Y-valve should be closed.)

7. Prime the pump completely, using either the hand primer or the bucket method. When the hand primer is used, operate the plunger rapidly, with full strokes, until it suddenly becomes hard to pump; this indicates that the air is exhausted from the pump and water has entered the pump. When the bucket method of priming is used, open the filler cap on the pump housing and use buckets or a hose to fill the housing completely with water. (NOTE: When an eductor is used, priming consists of filling with water the suction hose, the pump housing, and the pressure hose to the eductor. This cannot be accomplished

with the hand primer; the bucket method of priming is, therefore, necessary.)

8. Prime the carburetor on the engine by making four strokes of the plunger on the control panel. (See fig. 16–5.)

9. Place the knotted end of the starter rope in the notch of the starting pulley on the flywheel; wind the rope around the pulley.

10. Pull the starting rope strongly and steadily to the full length of the rope. If the engine fails to start with two pulls on the starting rope, push the carburetor-primer plunger once; then, pull the rope again. If the engine starts and immediately stops, push the primer, start the engine again, and keep priming as necessary until the engine warms up.

ROUTINE DURING OPERATION OF THE P–500.—After the engine starts, the following steps should be taken:

1. Make sure that the pressure gage (located on the control panel) registers the specified increases in pressure.

2. When the pressure gage registers 75 psi or more, slowly open one of the Y-valves. (When the eductor is in use, the Y-valve connected to the eductor must be open all the time. Hence, only the other Y-valve can be opened after pressure has built up.)

3. Readjust the carburetor needle valves so the engine operates best. (The normal setting of the slow-speed needle is one full turn open from closed position; the normal setting of the high-speed needle is 13 notches open, or unscrewed, from the closed position.) Note the readjusted settings for future reference.

4. Adjust the water pressure to the desired value by operating the pressure regulator.

5. If additional output is required, open the second Y-valve. (This Y-valve is not available when the eductor is used. See item 2 above.)

6. Watch the pressure gage and the temperature indicator. If the temperature indicator moves into the "dangerous" (red) zone of the dial, the unit should be stopped.

7. After the pump has operated at full capacity, for about one hour, the fuel supply in one tank will be almost exhausted; this condition will be indicated by the irregular operation of the engine and by a lowered position of the float-pin in the carburetor bowl. Turn the fuel valve from the empty tank to the full tank.

Do not operate the engine without pumping water; the engine is cooled by water taken from the pump. When the pump is used for pumping large volumes of water at comparatively low pressure (as in the pumping of bilges or of flooded compartments), do not permit the discharge pressure of the pump to drop below 35 psi; otherwise, the pressure regulator may not work properly and the engine may not be properly cooled.

STOPPING AND RESTARTING THE P–500.—To stop the unit, push and hold the STOP button on the control panel until the engine comes to a full stop. When the unit is to be restarted shortly after it has been stopped, it may be hot or, at least, warm. In this case, if the Y-valves were closed before the pump was stopped and if the foot valve and all hoses and hose connections are tight, the pump will hold its prime and take suction when the engine is started. If the pump should fail to do this, the hand primer may be operated while the engine is running. (CAUTION: Do not run the engine too long without full prime and pressure, or it will overheat. Watch the temperature indicator.) When the pump has prime, proceed with operations 8 through 10 of the starting instructions and 1 through 7 of the operating routine. Note, however, that less carburetor priming will be necessary when the engine is warm; be careful not to flood the carburetor.

Firemain System and Isolation Valves

As a Fireman, you have been introduced to the firemain systems used aboard Navy ships. As an Engineman, you

will be required to know the location of the principal isolation valves of the firemain system in the engineering spaces and adjacent spaces on your ship. The location of the valves used to isolate sections of the firemain varies from one ship to another. In general, isolation valves are located in the firemain proper, in the risers, and in horizontal leads. In learning the location of isolation valves on your ship, study the piping diagram of the firemain system. Make a sketch of the system, noting particularly the location of each valve.

To avoid confusion and to eliminate the possibility of error when sections of the firemain are being isolated, all important valves in the firemain system are generally marked with identification numbers. If all engineering personnel know both the location and the identification number of each valve, an order to close or open a particular valve can be given without time being taken to describe the valve's location.

HYDRAULIC EQUIPMENT

Some of the machinery with which you will work is electrohydraulically operated. This machinery includes steering gear, anchor windlasses, deck winches, capstans, and cranes. You will not be so much concerned with the maintenance of this machinery; you may be required, however, to operate and to stand watch on such auxiliary machines.

Notes on the Operation of Hydraulic Equipment

To gain the knowledge and ability necessary to efficiently operate and maintain hydraulic equipment will require much study and practical experience. A description of the various types of hydraulic equipment and a discussion of the principles underlying their operation is beyond the scope of this training course. Detailed information on the construction, operation, and maintenance of the hydraulic equipment on your ship should be obtained from the manufacturers' instruction books which accompany the equipment installation. The principles of operation of hydraulic equipment are discussed in the Navy training

courses, *Basic Machines,* NavPers 10624; and *Basic Hydraulics,* NavPers 16193.

As the operator of hydraulic equipment, you should keep in mind that hydraulic systems should be kept full of oil at all times. When a system is operated with too low an oil level, moisture may enter the system through the air vents, and cause rust. If corrosion is allowed to occur, the moving parts of the machine will eventually jam. An adequate oil level will also prevent air from accumulating in the system and hindering operation. When a hydraulic system is being filled with oil, the vent plugs at high points in the system should be left open until all the air escapes. After a hydraulic system has been filled, and before it is started under power, operate the machine slowly (by hand) so that any accumulations of air may be forced out of the system. If this precaution is not taken, the air is likely to be whipped into small bubbles within the oil when the machine is operated under power. Hand turning of the hydraulic gear should be continued as long as any air bubbles can be seen escaping from the hydraulic system.

When hydraulic equipment is located in exposed spaces under cold weather conditions, hydraulic pumps should be operated without load until the oil has reached a satisfactory operating temperature. In some cases it may be necessary to use a special, cold-weather, hydraulic fluid; and to operate special immersion heaters in the sump and in the storage tanks, before the hydraulic equipment can be operated.

Steering-Engineroom Watch

The steering gear of many ships includes hydraulic equipment. During your watch in the steering-engineroom, inspect the steering gear thoroughly at specified intervals. Feel the various parts of the equipment when it is in operation. When any part of the equipment is too hot to touch with the bare hand, the condition should be reported immediately to the Officer of the Watch, in the main engineroom.

Examine the equipment for possible binding, overloading, or lack of lubrication. Listen for new or unusual sounds, which may indicate loose parts or wear. Check to be sure that there is sufficient hydraulic fluid in the tanks, and that there are no leaks in any of the lines or fittings. Piping leaks are unusual; they may occur, however, following an unusual strain (such as that resulting from rough seas) on the ship's hull. Such leaks may be eliminated by tightening the flange bolts. Slow leaks at the packing glands of the rams are not objectionable; the small flow of hydraulic fluid provides lubrication. However, be sure to keep oil off the deck. When doing any work on the steering gear, keep the hydraulic fluid and all parts exposed to the oil clean and free of foreign matter. Be sure that all housings, grease fittings, and surfaces to be lubricated are properly filled, or lubricated in accordance with lubricating instructions. Be particularly careful of your hands when you are working around the moving parts of the equipment, especially when the equipment is in a confined space. Observe the prescribed safety precautions regarding the proper clothing to be worn when work is being done on operating machinery.

ELECTRICAL EQUIPMENT

Even though the care and maintenance of electrical equipment is the responsibility of an EM, you as an EN should be familiar with the precautions to be observed when you are working around electrical equipment. Safety precautions must always be observed by any persons working around electrical circuits and equipment, in order that injury caused by contact with an electrically charged object may be avoided.

Electric shock due to contact with an energized circuit can cause serious injury. Even low-voltage circuits (115 volts and below) can cause death upon contact, especially when current passes through the chest. Shipboard conditions are particularly conducive to severe shocks because (1) the body is likely to be in contact with the ship's metal structure, and (2) the body resistance to electricity

may be low because of perspiration or damp clothing. Extra care is therefore needed when you are working in the vicinity of electric circuits on board ship.

Extreme care should be exercised to prevent short circuits. Short circuits may be caused by accidentally placing or dropping a metal tool, a ruler, a flashlight case, or some other conducting article across an energized line. The arc, and the fire which may result, from even relatively low-voltage circuits may cause extensive damage to equipment and serious injury to personnel.

Safety precautions are posted in the vicinity of electrical equipment. If these simple precautions are observed, injury or accident will seldom occur when you are working around electrical equipment. When working in the vicinity of electrical equipment, keep in mind that electricity strikes without warning; that hurrying reduces caution and invites accidents; that taking chances is an invitation to trouble; and that every electrical circuit is a potential source of danger.

Even when safety precautions are carefully observed, accidents may occur. You should be familiar, therefore, with the procedures to be followed when rescue from electrical contact is necessary, and when injuries from electricity have been received. Rescuing a person who is in contact with an electrically charged object is likely to be a difficult and dangerous job. Extreme caution must be used; otherwise, you may be electrocuted yourself. You must not touch the victim's body, the charged object, or any other object which may be conducting electricity.

When rescuing a person from an electric contact you should, first of all, look for the switch. When you find the switch, shut off the current immediately. Do not spend much time hunting for the switch, however; every second is important. If you cannot find the switch readily, try to remove the victim's body from the electrically charged object with a dry, non-conducting object, such as a stick, a pole, an oar, or a board. It may be possible to use dry rope or dry clothing to pull the wire away from

the victim. You can also break the contact by cutting the wire with a wooden-handled axe, but this is extremely dangerous; the cut ends of the wire are likely to curl and lash back at you before you have time to get out of the way. When you are trying to break an electrical contact, always stand on some nonconducting material, such as a dry board, dry newspapers, or dry clothing.

The passage of electric current over the skin or through the body may result in asphyxiation, burns, and shock. Asphyxiation is the primary danger and is likely to occur when the skin is wet. Burns are most likely to occur when the skin is dry. Shock (a serious disturbance of the blood flow) accompanies or follows asphyxiation and burns.

When someone receives injuries from electricity you should proceed as follows:

1. Deenergize the circuit or release the victim from contact. Avoid unnecessary danger to yourself by observing all appropriate precautions.

2. If the victim is not breathing, treat for asphyxiation. Begin artificial respiration immediately. Keep the victim quiet after normal breathing is reestablished. As the victim is recovering, he may go through a period of frenzied violence.

3. Treat the victim for shock. Keep him lying down, with his head slightly lower than his feet. Keep the victim warm, but do not overheat him. (Note: Any person who has suffered an interruption of breathing should not be given morphine.)

4. Treat the victim for burns, if necessary. For information on the treatment of burns, see *Standard First Aid Training Course,* NavPers 10081. That reference also gives information on the methods of artificial respiration, and additional information on factors related to injuries from electricity.

QUIZ

1. What is meant by compressor displacement?
2. Vessels which require only a small supply of high-pressure air are equipped with compressors having how many stages?
3. What causes automatic action of the air valves on modern air compressors?
4. What keeps compressed air from forcing the oil back into the cylinder lubricator of an air compressor?
5. How is the oil which lubricates the running gear of an air compressor returned to the reservoir?
6. On late model water-cooled air compressors, what provision is made to regulate temperature in the oil cooler without affecting the temperature in other parts of the cooling system?
7. What function is performed by the intercoolers of an air compressor?
8. Why are the intercoolers and aftercoolers of an air compressor fitted with separators?
9. When the automatic shutdown device stops the compressor, will the compressor restart automatically?
10. What type of control is installed when a compressor is required to furnish a continuous supply of air?
11. Is the compressor control device that is used to ensure a continuous supply of air actuated by changes in (a) temperature or (b) pressure?
12. What can be accomplished with dual control on an air compressor?
13. Describe briefly the path of air through a three-stage compressor, by listing, in the proper sequence, the parts through which the air flows.
14. Why should benzine, kerosene, and similar oils never be used to clean the filters, cylinders, or air passages of an air compressor?
15. From what three general causes may explosions occur within an air-compressor element, the discharge line, or the air receiver?
16. When the temperature of the air discharged from any stage of compression exceeds the maximum operating temperature, should (a) the amount of cooling water be increased, (b) the setting of the relief valve on the water side of the intercooler be adjusted, or (c) the compressor be secured?
17. When work is being performed on the compressor, should the valves between the air compressor and the receiver be opened or closed?
18. What is the most probable cause of trouble when a P-500 pumps fails to take suction as the pump is started?

19. How is lubricating oil supplied to the engine parts on a P-500 pump?
20. What is indicated when the hand primer of a P-500 pump suddenly becomes hard to pump?
21. Give two symptoms which indicate that the fuel supply of a P-500 pump is nearly exhausted.

CHAPTER 17

OPERATING SHIPBOARD REFRIGERATION AND AIR CONDITIONING SYSTEMS

As a Fireman, you have already been told of the need for refrigeration aboard ship. Many of the terms related to the theory of refrigeration, the mechanical refrigeration process, and the type of refrigeration and the refrigerant commonly used in shipboard installations have been discussed in *Fireman,* NavPers 10520–A. If you need some review on the fundamentals of refrigeration, refer to *Fireman,* NavPers 10520–A. In using that training course, you will not find all refrigeration information, particularly the discussion of the terms related to refrigeration, listed under the heading of refrigeration. Use the index as a means of locating information on such specific items as heat, heat flow, and heat measurement.

As an EN3, you will be required to operate refrigeration and air conditioning systems. You will learn how to operate these systems, under the supervision and guidance of a petty officer who knows the construction of each system and how the system operates. You will learn about the construction and the principles of operation of these plants through practical experience and further study. Details on the refrigerants in common use and on the construction, operating principles, and maintenance of refrigeration and air conditioning systems is presented in more advanced training courses for Enginemen. The information presented in this course is general in nature;

it deals principally with the starting, operating, and securing procedures for typical systems. Only general information is provided because no one set of procedures is applicable to all refrigerating and air conditioning installations. The information provided in this chapter should aid you, however, in becoming familiar with the operating procedures which apply to your plant. When you are operating and maintaining any specific machine or system, follow the recommendations made by your leading petty officer, and the instructions posted near the equipment and those given in applicable operating and maintenance manuals.

A TYPICAL SYSTEM

Navy uses of refrigeration equipment include the refrigeration of ship's stores and cargo; water-cooling for film development; the making of ice and ice cream; the hardening of foods for storage; the cooling of food-storage spaces; the operation of drinking-water coolers; and the air conditioning of spaces where personnel efficiency, health, safety, or the operation of equipment is endangered by either high temperature or humidity, or by both.

Of the various types of refrigerating systems used by the Navy, the plant which uses Freon-12 is the most common. The information given in this chapter applies principally to Freon-12 systems.

The cycle of operation and the main components of a Freon-12 system are basically the same in both a refrigeration plant and an air conditioning system. The principal components and the piping arrangement of a basic, Navy-type refrigeration or air conditioning plant are shown in the schematic drawing, figure 17–1.

Note that, as pointed out in *Fireman,* NavPers 10520–A, the principal components of the system are the compressor, the condenser, the receiver, and the cooling coil (evaporator). Some systems include multiple compressors and multiple cooling coils. Any system requires additional

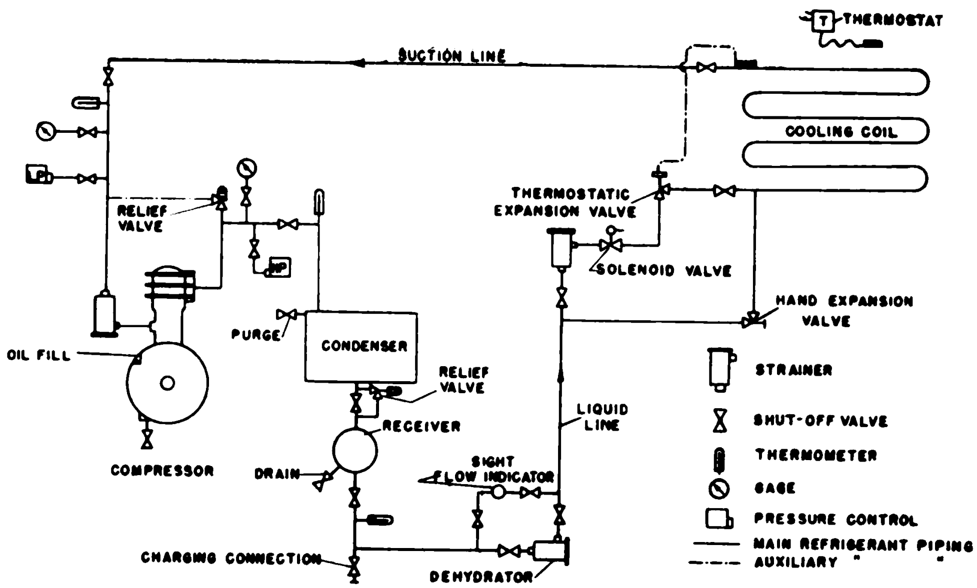


Figure 17–1.—Components and piping of a basic refrigeration or air conditioning system.

equipment, beyond the principal components, to complete the plant. Such equipment includes piping, pressure gages, thermometers, various types of control switches and valves, strainers, and an electric motor and connecting wires. Since one of your duties will be to operate a plant composed of the parts and equipment listed, a brief description of such a typical Freon-12 system is presented here. A general knowledge of the plant will make the operating procedures presented later in this chapter more meaningful. For the purpose of this discussion, the components and related equipment of the plant are considered as forming three circuits: refrigerant, cooling, and electrical. (Refer to figure 17–1 as you study the following sections of this chapter.)

Refrigerant Circuit

The refrigerant flows, as a liquid, from the receiver to the cooling coil; and, as a gas, from the cooling coil through the compressor to the condenser, where the gas changes to a liquid again. From the condenser, the liquid is discharged to the receiver for recirculating. This sec-

tion points out the function of the principal components and other parts of the refrigerant circuit.

RECEIVER.—This component provides a space for the accumulation of the liquid Freon-12. Stop valves are provided at each side of the receiver. A relief valve bypasses the receiver shut-off valve. The relief valve permits the liquid to expand to the condenser in the event the receiver is secured when it is full of liquid.

MAIN REFRIGERANT LIQUID-LINE.—This line provides for the passage of the liquid Freon-12 from the receiver to the cooling coil. In addition to a stop valve, a THERMOMETER is usually placed in the main line adjacent to the receiver. A PRECOOLER may be used, after the receiver, to reduce the temperature of the Freon liquid. The precooler usually consists of a shell, which contains the liquid to be cooled, and a fabricated coil, which constitutes the cooling surface. In some installations, a heat interchanger is used as a precooler; in this case, the liquid is cooled by being brought in contact with the tubing which contains the lower-temperature, suction gas flowing from the cooling coils to the compressor.

Most Freon-12 systems installed aboard ship are provided with a CHARGING CONNECTION in the main liquid-line. This connection permits charging liquid refrigerant into the system. The charging connection is located just ahead of the DEHYDRATOR, in a bypass line. The dehydrator is used to remove any moisture which enters the system with the liquid refrigerant. The dehydrator consists of a cylindrical shell which contains a drying agent (moisture-absorbing substance) ; the drying agent is usually enclosed in a removable cartridge. Filters and strainers are provided, at the ends of the cartridge, to prevent small particles of the drying agent from passing into the system. The dehydrator is put in use when the system is being charged, after repairs have been made to the system, and at any time that moisture is believed to be present in the system.

A SIGHT-FLOW INDICATOR is usually installed in the main liquid-line. This indicator permits viewing the liquid, as it passes from the receiver to the cooling coil; the condition of the liquid can thus be determined. The indicator is provided with bypass piping and valves which allow the indicator to be isolated when repair or replacement of it is necessary.

The sight-flow indicator assembly may include a "King" solenoid valve, installed next to the indicator. The valve functions to stop the flow of liquid from the receiver when the compressor stops because of abnormal operation of the system.

From the dehydrator and sight-flow indicator assemblies, the liquid refrigerant flows through a feeder connection (from the main liquid-supply line) to the LIQUID STRAINER. The filtered liquid is discharged through a SOLENOID STOP VALVE. This valve is designed to stop the flow of liquid refrigerant to the cooling coil when the space being cooled has reached the desired temperature, and to permit flow of the refrigerant liquid when cooling is required. From the solenoid valve, the liquid flows to the THERMOSTATIC EXPANSION VALVE. This valve controls the quantity of refrigerant admitted to the cooling coil, and reduces the pressure of the refrigerant to that maintained in the coil. The thermostatic expansion valve is designed to feed the coil the refrigerant necessary for efficient operation.

A bypass line equipped with a HAND EXPANSION VALVE is installed around the strainer and cooling-coil liquid-control valve assembly. The manually operated expansion-valve bypass permits isolating the strainer and the control-valve assembly for repair or cleaning. In some installations, the shut-off valve, hand expansion valve, strainer, solenoid valve, and thermostatic expansion valve are combined into one compact assembly, called the LIQUID CONTROL MANIFOLD. The liquid refrigerant flows from the control assembly into the cooling coil.

COOLING COIL (OFTEN REFERRED TO AS EVAPORATOR).—

The location of the coil will depend upon the purpose of the system. For example, the coil may be found in a cold storage compartment, in an ice-making tank, in an air-cooling unit, in a water-cooling unit, in a powder magazine, in an ice cream freezer, or in a hardening cabinet. The coil is usually made of bare tubing.

The liquid refrigerant in the coil is maintained at a pressure sufficiently low so that the boiling temperatures of the refrigerant is lower than the temperature of the substance being cooled. This difference between the temperature of the refrigerant and that of the substance being cooled causes heat to flow from the substance being cooled, through the metal wall of the coil, to the liquid refrigerant within the coil. The liquid refrigerant is already at its boiling point, but the liquid is capable of absorbing its latent heat of vaporization (by which it is changed from a liquid to a gas without change in temperature).

COMPRESSOR SUCTION LINE.—The gas formed in the cooling coil flows to the compressor through the compressor suction line. This line may include suction-pressure regulating valves, an interchanger, a suction-line stop valve, a suction strainer, a thermometer, and a pressure gage.

When a refrigerating system includes SUCTION-PRESSURE REGULATING VALVES, they are installed at the outlet of the cooling coils. Pressure-regulating valves are designed to maintain a substantially constant pressure within the cooling coil; this pressure is higher than the suction pressure downstream and is independent of suction-pressure fluctuations. A pressure-regulating valve functions to decrease the difference between the temperature of the component and that of the surface of the cooling coil.

Suction-pressure regulating valves are used in installations where two or more spaces served by a single compressor are maintained at different temperatures. Each space requires a coil and a valve. Suction-pressure regu-

lating valves are also used in individual refrigerating units, such as water coolers, where the temperature level of the coil must always be maintained above freezing.

In low-temperature applications of refrigerating systems, HEAT INTERCHANGERS may be located in the suction line near the evaporator coil. In an interchanger, the relatively cold gas flowing to the compressor, from the cooling coil, is used to cool the liquid refrigerant flowing, through the liquid line, to the cooling coil. This transfer of heat serves two purposes. Any unvaporized liquid in the suction line is vaporized by the heat given off by the liquid refrigerant; this prevents the refrigerant, in its liquid state, from entering the compressor and causing damage. Also, the refrigerant in the liquid line is cooled sufficiently to prevent any tendency of the liquid refrigerant to flash into gas.

Between the suction-line stop valve and the compressor, a THERMOMETER and a PRESSURE GAGE are provided to indicate the conditions under which the compressor is operating. Standard thermometers are used; however, all Freon-12 pressure gages are provided with two scales. One scale indicates pressure in psi (or in inches of mercury, for pressures below atmospheric); the other scale indicates the corresponding saturated temperatures of the refrigerant, in degrees Fahrenheit. The thermometer will indicate a higher temperature than that corresponding to the suction pressure (indicated by the gage) because the refrigerant vapor becomes superheated in the coils and by heat leakage through suction-line insulation, as the vapor flows from the evaporator to the compressor.

The suction-line intake connection of the compressor is provided with a SUCTION STRAINER. The strainer protects the moving parts of the compressor by removing foreign particles which may enter the refrigerant circuit when the piping system is opened for any reason.

COMPRESSOR.—The liquid refrigerant which has been boiled to a gas in the cooling coil cannot absorb more heat until the heat absorbed during the process of vaporization

has been removed, and the gas has been condensed to a liquid. The gas drawn into the compressor is at a temperature of about $-5°$ F. The cooling medium (water or air) is usually available at temperatures between 40° and 100° F. In order that the cooling medium (at these temperatures) can serve to condense the refrigerant again, it is necessary that the pressure of the refrigerant gas be raised sufficiently so that its condensing temperature is higher than that of the cooling medium. Since an increase in pressure causes a proportional rise in temperature, and since a fluid vaporizes and condenses at a temperature which depends upon the pressure to which the fluid is subjected, raising the pressure of the refrigerant gas enables it to be condensed at the temperature of the available cooling medium. The compressor raises the pressure of the refrigerant gas sufficiently high to permit heat transfer and condensation in the condenser.

COMPRESSOR DISCHARGE LINE.—The high-pressure, refrigerant gas discharged from the compressor flows to the condenser through the compressor-discharge line. This line includes a STOP VALVE and a spring-loaded RELIEF VALVE. The relief valve is located in the line between the compressor-discharge connection and the stop valve; it is provided to protect the high-pressure side of the circuit from excessive pressures. The compressor-discharge line also includes a compressor-discharge PRESSURE GAGE and a compressor-discharge THERMOMETER, which indicate the pressure and the temperature of the compressed gas. The compressor-discharge line terminates at the refrigerant condenser.

CONDENSER.—The compressed gas passes into the condenser; here, due to the temperature difference between the refrigerant gas and the condenser cooling medium, heat from the gas passes through the metal walls of the condenser tubes and into the cooling medium. The refrigerant gives up its latent heat of vaporization, in addition to the heat which is absorbed during the compression process. The refrigerant gas is cooled to its condensing

temperature at the pressure existing in the condenser; it then condenses, giving up its latent heat of condensation. The resulting liquid flows to the receiver to complete the refrigerant circuit.

Cooling Circuits

Water and air are used as cooling media; they remove the heat which is absorbed by the refrigerant in the cooling coil and in the compressor. The condensers of all, large, Freon-12 refrigeration and air conditioning systems are water-cooled. Units of relatively small capacity utilize air-cooled condensers.

WATER COOLING.—Water-cooled, Freon-12 CONDENSERS are of the multipass, shell-and-tube type; in these condensers, the circulating water flows through the tubes. The refrigerant gas is admitted to the shell and condenses on the outer surfaces of the tubes. A schematic drawing of a typical refrigerant-condenser and circulating-water piping is shown in figure 17–2.

Circulating water may be supplied to the refrigerant condenser either by individual pumps taking suction from the SEA or by a branch connection from the ship's FIRE AND FLUSHING MAIN.

The circulating-water line includes a REGULATING VALVE, which controls the quantity of water flowing through the line. This valve is actuated by the pressure of the refrigerant in the compressor-discharge line. A PRESSURE GAGE is also installed in the circulating-water line to the condenser. The temperatures of the water entering and leaving the condenser are indicated on standard THERMOMETERS. Valves and plugs are provided in condenser water-boxes for draining and venting. Cutout valves are installed in the pressure lines to all control devices and indicating devices; by the use of the cutout valves these units may be isolated, temporarily, for repair or test.

AIR COOLING.—Air-cooled condensers are used on small refrigeration systems where compressor-motor require-

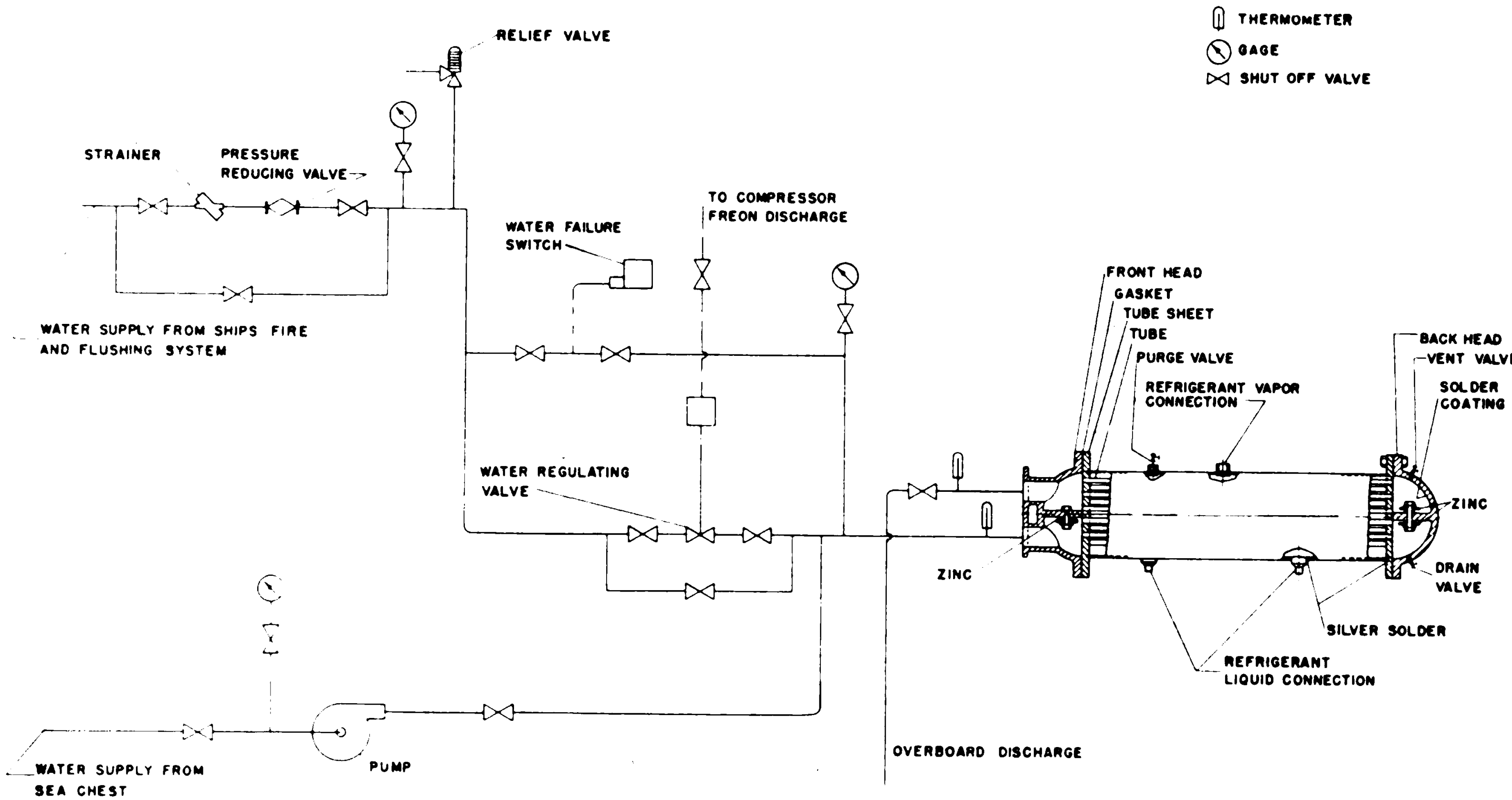


Figure 17-2.—Refrigerant condenser and water piping.

ments do not exceed 2 horsepower, and where adequate ventilation is provided. Air-cooled condensers are generally mounted on a common base with the compressor, the motor drive, and accessories. A small refrigeration system so arranged is usually called a condensing unit.

The condenser is located directly in front of the motor pulley and the compressor flywheel. A fan is usually provided to circulate air across the condenser; a sheet metal casing, or cowl, is usually provided to direct the flow of air through the condenser in the most effective manner. The fan provides sufficient circulation of air for carrying away the heat of condensation if the condensing unit is located in an open, well-ventilated space. Units located in confined spaces require ventilating ducts to supply an adequate volume of fresh air to the condenser, and a discharge vent to remove the air heated by the condenser. Unless proper ventilation is provided for small refrigeration units located in confined spaces, refrigerant condensing pressures will develop, cooling capacity of the unit will decrease, and the compressor motor may become overloaded.

Electrical Circuit and Controls

Refrigeration and air conditioning systems are equipped with electrically-interconnected control devices which provide completely automatic operation and control. Some of the control devices are related primarily to the refrigerant circuit; other devices are related to the circulating-water circuit. All operating and safety control devices are electrically interconnected with the compressor motor and the pump controllers. Schematic wiring diagrams of typical, electrical-control circuits used with refrigeration systems are shown in figure 17–3.

REFRIGERANT CIRCUIT CONTROLS.—In some installations, a KING SOLENOID VALVE is installed next to the sight-flow indicator in the main liquid line and within the indicator bypass-assembly. The valve is electrically connected to the compressor-motor starter-control circuit. The valve will be energized so as to remain open when the equipment is

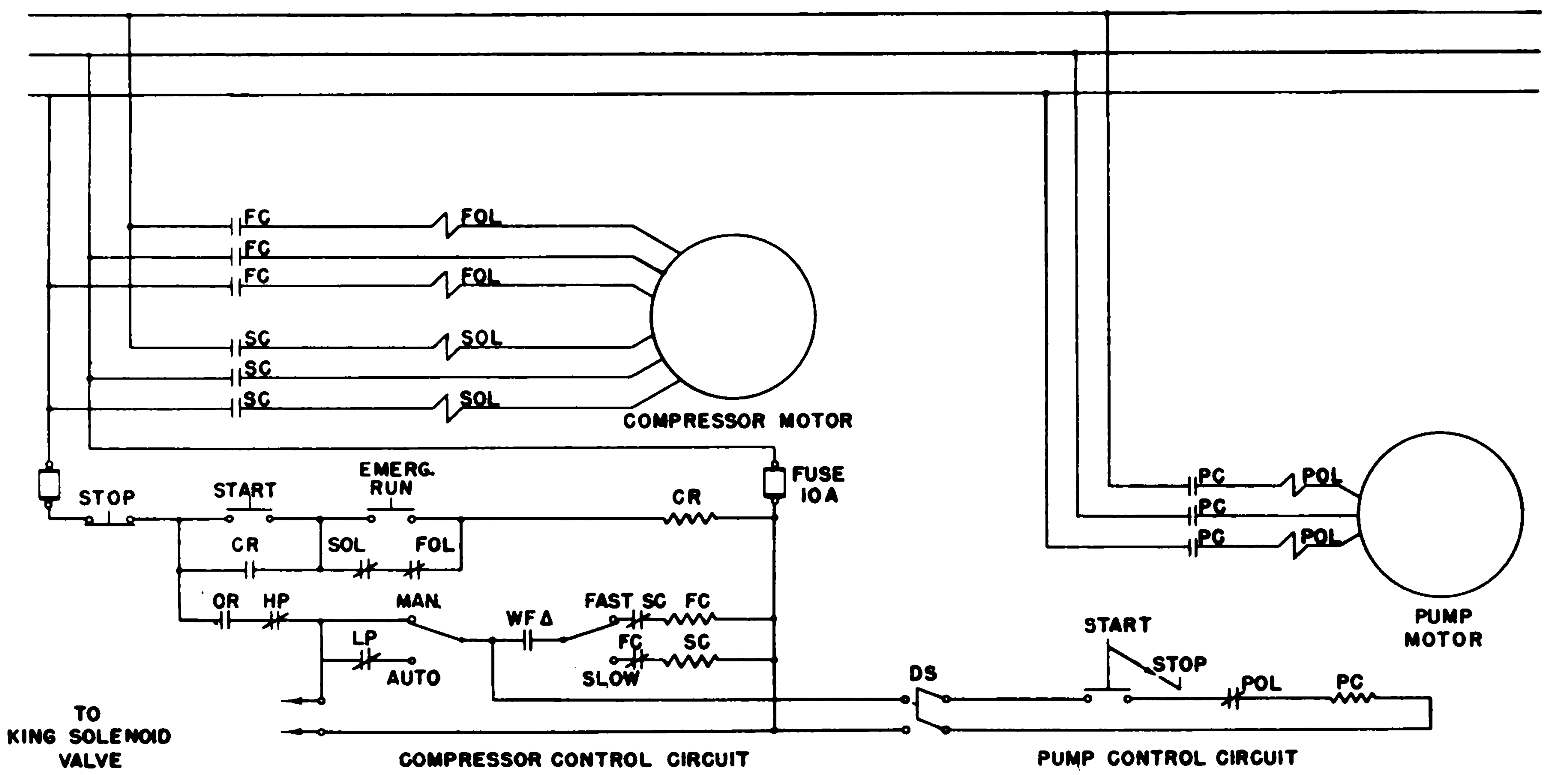
under normal operation with suction-pressure control; it will be de-energized so as to close when the compressor motor is stopped manually, or when the control or overload relays or the high-pressure cutout open automatically.

The filtered, liquid refrigerant is discharged, from the strainer, through the SOLENOID STOP VALVE. This valve is usually actuated electrically under the control of a thermostatic switch which is responsive to temperature change in the space being cooled; it may be manually controlled by a toggle switch in some applications.

In addition to the pressure gage and the thermometer in the compressor suction line (between the suction-line stop valve and the compressor), a connection leading to the SUCTION-PRESSURE CONTROL SWITCH is provided. Often called the LOW PRESSURE CUTOUT, this is essentially a single-pole, single-throw, electrical switch; it is used mainly to control starting and stopping of the compressor.

The refrigerant suction pressure, acting on the metallic bellows of the power element of the switch, produces movement of a lever mechanism which operates electrical contacts. A rise in pressure closes these switch contacts; this completes the pilot circuit of the motor controller, which, in turn, starts the compressor automatically. As operation of the compressor gradually decreases the suction pressure, the movement of the switch linkage reverses until the contacts are separated at a predetermined, low-suction pressure; the motor controller pilot circuit is thus broken and the compressor is stopped.

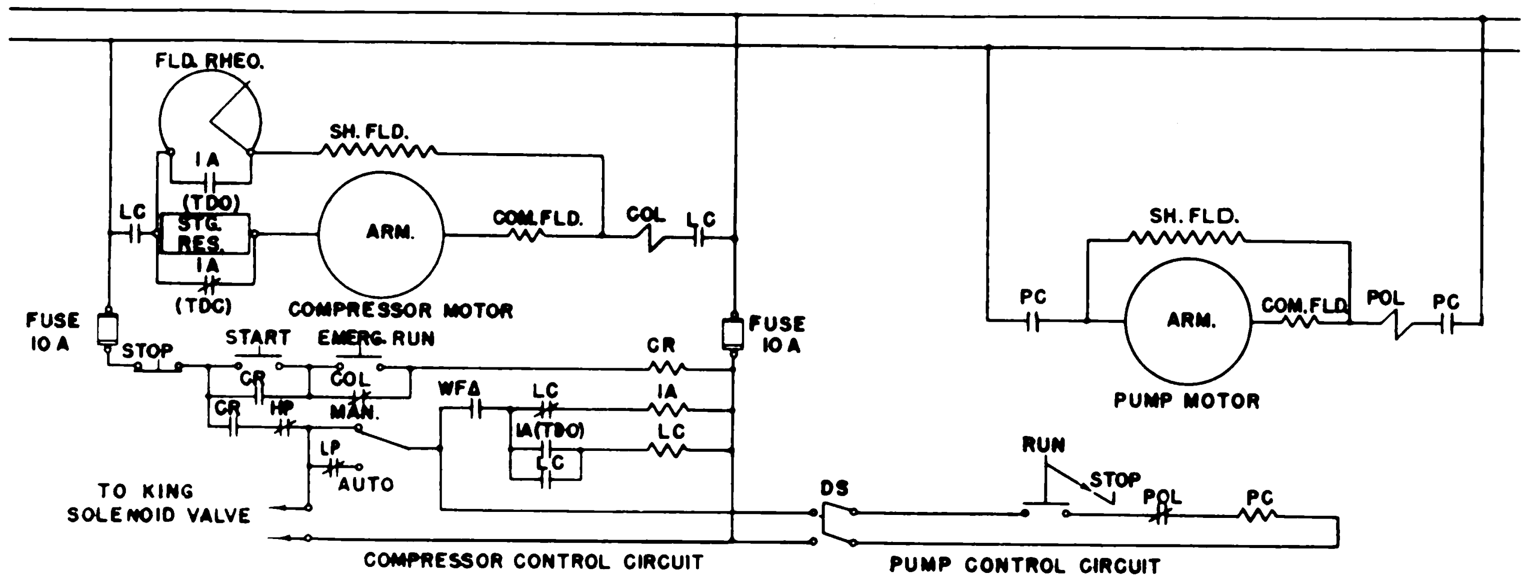
To provide protection against excessive pressures on the high-pressure side of the system, a HIGH-PRESSURE CUTOUT SWITCH is connected to the compressor-discharge line. The high-pressure cutout switch breaks the motor-control circuit and stops the compressor motor before the discharge pressure becomes sufficiently high to operate the relief valve. The relief valve functions only if the high-pressure switch fails to operate properly or if it is improperly adjusted. A stop valve is installed in the pres-



TYPICAL ELECTRICAL CIRCUIT FOR 3 PHASE

ALTERNATING CURRENT

Figure 17–3.—Electrical control circuits of refrigeration systems.



TYPICAL ELECTRICAL CIRCUIT FOR DIRECT CURRENT

LIST OF SYMBOLS:

LC-COMPRESSOR CONTACTORS
PC-PUMP CONTACTORS
COL-COMPRESSOR OVERLOAD RELAY
POL-PUMP OVERLOAD RELAY
FOL-COMP. FAST OVERLOAD RELAY
IA-COMPPESSOR ACCELERATING CONTACTOR
CR-CONTROL RELAY
HP-HIGH PRESSURE SWITCH
LP-LOW PRESSURE SWITCH
SOL- COMPRESSOR SLOW OVERLOAD RELAY
TDO- TIME DELAY OPENING CONTACT
WF-WATER FAILURE SWITCH
DS-DISCONNECT SWITCH
FC-COMPRESSOR FAST CONTACTOR
SC-COMPRESSOR SLOW CONTACTOR
TDC-TIME DELAY CLOSING CONTACT

Figure 17—3.—Electrical control circuits of refrigeration systems.—Continued.

sure line to the high-pressure cutout switch to isolate it from the system in case of derangement, and when the refrigerant system is being tested at high pressures.

WATER CIRCUIT CONTROLS.—When a pump is used to provide condenser cooling-water, the PUMP-MOTOR CONTROLLER is electrically interconnected with the compressor-motor controller so that the circulating-water pump starts and stops automatically with the compressor. Connections in the circulating-water line from the pump and the fire main lead to a WATER-FAILURE SWITCH. This pressure-actuated switch stops the compressor motor automatically in the event of failure of the circulating-water supply. If the flow of condenser circulating-water is interrupted, the pressure in the line decreases sufficiently so that the switch opens; this opens the pilot circuit of the compressor-motor controller and stops the compressor. When the flow of condenser circulating-water is reestablished, pressure in the line increases, the switch closes the controller pilot-circuit, and the machine restarts. Should this switch fail to function, the refrigerant pressure in the condenser would quickly build up to the point where the high-pressure cutout switch would function.

ELECTRICAL INTERCONNECTION OF CONTROLS.—The operating and safety controls are electrically interconnected with the controllers of the compressor and the pump motor. The controllers of the compressor and the pump motor may be mounted separately or they may be combined within a common enclosure. The motor controllers are generally furnished with operating stations, which are either located on the cover of the controller or are mounted separately. An operating station includes an "automatic-manual" selector; and "start," "stop," and "emergency-run" switches. Automatic operation is obtained, through the "automatic-manual" switch, by electrically connecting the suction-pressure control when the compressor motor is being started or stopped. Manual operation is obtained, through this switch, by electrically

bypassing the suction-pressure control; manipulation of the "start" and "stop" switches is then required. In either position, the "automatic-manual" switch connects all safety controls. The "start" and "stop" switches provide a means of manually opening and closing the pilot circuit. The "start" switch for the compressor motor-controller pilot-circuit is usually a momentary-contact type switch, the closing of which provides the initial electrical input in manual starting; the switch reverts to its normally-open position after starting. The "start" switch for the pump-motor controller is generally a maintaining-contact type switch, which is normally closed during starting and operation. The "emergency-run" switch permits emergency operation in which the safety devices are bypassed electrically.

Schematic wiring diagrams for the control circuits of typical refrigeration systems with water-cooled condensers are shown in figure 17–3. If water is supplied to water-cooled condensers from the ship's fire and flushing main exclusively, the pump circuit shown is not applicable. When the condensers of a refrigeration system are air-cooled, the electrical circuit is the same as shown, except that the water-failure switch and the condenser-water pump circuit are not applicable.

OPERATING PROCEDURES

Since refrigeration plants used for refrigeration and those used for air conditioning are basically the same, the following information on operating procedures applies, in general, to plants used for either purpose.

Prestarting Instructions

When a refrigeration or air conditioning system is being prepared for starting, the procedure (AS APPLICABLE to a particular installation) is as follows:

1. Open all refrigerant system valves except the following: those valves which lead to the atmosphere; the bypass valves around the liquid-control valve assemblies and the suction-pressure control valves; the dehydrator-cutout valves; the compressor-suction line valves; the

compressor-discharge line valves; the condenser-outlet valve; and the stop valves in the condenser cross-connecting lines (if installed).

2. Start the fan motors on all forced-air coolers; see that an adequate amount of air is being delivered.

3. On water-cooler applications (soda fountains, drinking-water coolers, process-water coolers), admit the water to be cooled and purge the water circuit of air.

4. See that all stop valves in the circulating-water supply and the discharge lines for the Freon-12 condenser are open.

5. If water is taken from the fire main, make certain that the pressure-reducing valve ahead of the water-regulating valve is adjusted to provide a water pressure of 30 psi or less ahead of the water-regulating valve.

6. When no pressure-reducing valve is installed, regulate the fire-main connection stop valve manually so that the required water pressure ahead of the water regulating valve is maintained.

7. When an individual circulating pump is used to supply condenser circulating-water, be sure that any valves which permit transmission of pump-discharge pressure to the water-failure switch are open.

8. If the compressor unit is equipped with an air-cooled condenser, make certain that the air flow passages to the condenser are unobstructed, and that the air-circulating fans are clear.

9. Open the compressor discharge-line valve, the stop valve in the line connecting the condenser and the liquid receiver, and the main liquid-Freon-line valve.

Starting the Compressor and Operation in Manual

Too much stress cannot be placed on the need for thoroughness and care at the time the compressor is started. Bent crankshafts, distorted valves, and blown gaskets are a few of the casualties which may occur if applicable procedures and precautions are not followed. After accomplishing or checking the items listed under prestarting instructions, proceed as follows:

1. Set the "automatic-manual" selector-switch in the MANUAL position.

2. Close the maintaining-contact "start" button in the pump control circuit to prepare the pump motor for starting.

3. Close the momentary-contact "start" switch in the compressor control circuit to start the pump motor and to energize the "King" solenoid valve circuit.

As the pump circulates the water, the water-failure switch closes automatically and completes the circuit to the compressor-motor contactor coil. When this circuit is closed, the compressor motor starts. In installations where a pump motor and a pump control circuit are not installed, closing the momentary-contact "start" button energizes the compressor control circuit and starts the compressor motor.

4. Start and stop the motor and compressor several times, by manual control, to check their operating condition. (Details of proper operation for a given system should be obtained from the applicable manufacturer's instruction book.)

5. After it has been determined that the motor and the compressor are in operating condition, start the machine and crack the compressor-suction valve slowly so as to limit the quantity of suction gas handled by the compressor.

The suction gage should be watched as the compressor-suction valve is opened. The valve should be opened, gradually, at a rate such that there will be neither a rapid fluctuation in suction pressure nor a rapid drop of pressure in the compressor crankcase.

6. If lubrication of the compressor is forced feed, check the pressure on the oil-pressure gage.

Unless specific instructions indicate otherwise, the oil pressure should be between 15 and 30 pounds above compressor-suction pressure within a few seconds after the compressor is started.

7. Make certain that the proper quantity of circulating water is flowing through the condenser before the compressor-discharge pressure reaches 125 psi.

In systems not equipped with water-regulating valves, normal operating conditions generally produce condensing pressures of less than 125 psi, since the condensing-water temperature is usually less than 85° F. In systems equipped with water-regulating valves, the valves should be adjusted to maintain the condensing pressure at 125 psi. When the valves are so adjusted, the quantity of cooling water required decreases rapidly with decreasing circulating-water temperatures. In systems equipped with air-cooled condensers, condensing pressures may exceed 125 psig when the temperature of the surrounding air is higher than normal.

Operation in "Automatic"

After the prescribed operating pressures and temperatures have been established with the selector switch set at MANUAL, the switch should be set in the AUTOMATIC position. When the switch is in the position for automatic operation, the suction-pressure control is so connected, by electrical means, that it starts and stops the compressor automatically, on the basis of load conditions. If the automatic-control valves and switches are in proper adjustment, the operation of the plant, after proper starting, will be entirely automatic. The fact that a plant is operating automatically does not relieve the operator of the responsibility of knowing what to do when controls do not function or of the responsibility of making frequent checks during his watch to see that the plant is continuing to operate efficiently.

OPERATION WITH FIRE MAIN WATER SUPPLY.—If condenser cooling water is obtained from the fire and flushing main instead of from a circulating water pump, the controller pilot-circuit pump-switch is opened manually when it is desired to deenergize the pump electrical circuit and thereby stop the pump motor. The water-failure switch

remains closed, whether or not the compressor is in operation.

CIRCULATING-WATER FAILURE.—Should the flow of circulating water to the condenser be accidentally interrupted while the compressor is in operation, the decrease in water pressure will cause the water-failure switch to open. This deenergizes the compressor-motor line contactor-coil, opens the line contactors in the motor power-supply lines, and stops the compressor.

EXCESSIVE CONDENSING PRESSURE.—When the compressor discharge-pressure becomes abnormally high, the high-pressure cutout-switch opens, deenergizing the line contactor-coils and stopping the motors (in the same manner as the opening of the water-failure switch does). When the condensing pressure returns to normal, the high-pressure switch closes and restarts the plant.

CIRCULATING-WATER CONTROL.—As a general rule, the quantity of water flowing through the condenser should not exceed 6 gallons per minute per ton of refrigeration. (Ton of refrigeration: the basic unit of measurement of the cooling effect of mechanical refrigeration; equal to the removal of 12,000 Btu/hr., or 288,000 Btu/day; approximately equal to the latent heat required to freeze or melt 1 ton of ice/day.) Suitable precautions should be taken to assure that this limit on the amount of circulating water is not exceeded in service. Larger than normal quantities of circulating water produce correspondingly higher velocities in the water flowing through the condenser tubes. These higher velocities increase the erosion of the tubes and of the tube-sheet surfaces. If manual control of circulating-water flow is required, it should be accomplished by manipulation of the valve in the overboard-line from the condenser.

ACTION OF OVERLOAD RELAYS.—The power required to drive a given compressor is in relation to the suction pressure, assuming that discharge pressure is constant. An increase in suction pressure results in higher compressor capacity and higher power requirements. When

large increases in suction pressure occur in a plant designed for low suction pressure, the increased condenser loading (caused by increased compressor capacity) raises the condensing pressure, and the compressor tonnage capacity increases faster than the horsepower-per-ton decreases; thus, the total required horsepower input to the compressor is increased. When the refrigerating compressor of a new plant is first started after a prolonged and complete shutdown, the compartments to be cooled are warm; the refrigerant evaporating-pressure will, therefore, be much higher than normal. Under these conditions, the compressor motor may be overloaded; the unit should, therefore, be observed carefully during its first few hours of operation.

Should the compressor or the pump motors become overloaded to a dangerous degree while the plant is in operation, the overload-relay switches will be opened by overload devices located in the power lines to each motor. When either of the overload-relay switches open, the control-relay switches open and stop the motors. The overload relays must be reset before the motors can be operated again under automatic control. If either of the motors should develop a short circuit, the line fuses will usually blow before the overload relay trips out. Should the overload trip fail to function, it will be necessary to stop the compressor motor with the manual control when overheating occurs.

COMPRESSOR SHORT CYCLING.—The heat load of a refrigeration plant (that is, the amount of heat to be absorbed by the plant), regardless of the purpose for which refrigeration is required, will generally vary within wide limits; this variation will depend upon such factors as ambient temperatures, frequency of opening doors and hatches of compartments to be cooled, and the number of men in compartments to be cooled. The heat load of a cold-storage refrigerating plant is sometimes more than doubled when warm supplies, unfrozen meat, etc., are charged into the cold-storage spaces in large quantities.

The compressor unit must be designed to carry the maximum required heat load; it will operate at a fraction of its rated capacity, therefore, during a large part of its operating time. If the system's heat load is very small, the compressor need operate during only a small portion of the total time. When the compressor starts under a small load, the amount of refrigerant fed to the cooling coils may be even less than that required for the designed capacity of the machine at low-suction pressure. Under these conditions, the compressor rapidly reduces the suction pressure to the point where the low-pressure control switch opens and stops the unit; that is, the compressor short cycles. The tendency of the compressor to short cycle may be decreased by increasing the range between the cut-in and cut-out points of the low-pressure control switch; or, preferably, by reducing the capacity of the compressor.

The compressors in most Freon-12 refrigerating plant installations are provided with either adjustable-speed or two-speed motors. When the heat load for the plant is comparatively small, the setting of a switch which is provided at the motor controller is changed from normal, full-speed position to a fractional-speed position (usually one-half speed) ; the compressor's speed and capacity are correspondingly reduced. The shift from full speed to fractional speed is usually accomplished manually; specific instructions for making this change are included in the instruction book for the plant. Occasionally there is installed a low-pressure switch which automatically changes the motor speed as the compressor-suction pressure varies with changes in the heat load.

Another method of regulating compressor capacity, occasionally employed in Freon-12 plants installed aboard naval vessels, consists of bypassing the vapor pumped by one or more cylinders of a multicylinder compressor back to the suction line, instead of compressing it and discharging it to the condenser.

Some large Freon-12 compressors are provided with ports in the cylinder walls. These ports are above the top of the piston when it is at the bottom of its stroke; they communicate with the compressor-suction line through port-control valves, which are operated either manually or automatically. Capacity reduction is accomplished by opening the port-control valves; part of the cylinder vapor is thus bypassed before the remainder of the vapor is compressed and discharged to the condenser.

The latest refrigerating and air conditioning compressor units are provided with automatic capacity control mechanisms. The control mechanism prevents short cycling during periods of light loads; the mechanism also permits the starting of compressors without load. The capacity control automatically cuts cylinders out of operation by means of an oil pressure operated mechanism. The mechanism holds the suction valve disk open so that no gas can be compressed. The cylinders are unloaded consecutively as the suction pressure is reduced.

Standing Watch

The qualified watch stander on a refrigeration or air conditioning system is responsible for making routine checks on the entire system, and for taking such steps as are necessary to keep the system operating at maximum efficiency. This responsibility involves making the necessary adjustments to the pressure controls, the temperature controls, and the refrigerant-expansion valves; maintaining a log of plant operation; recognizing symptoms of inefficient operation, and knowing what corrective action to take; and performing maintenance and repair jobs on the system. Learning how to do all of the tasks related to efficient operation of a refrigeration or air conditioning plant will require much practical experience, and attentive observation of the procedures followed by personnel who are qualified in the operation and maintenance of the plant. As an EN3, your initial responsibilities will probably include checking temperatures and pressures, maintaining the plant's operating log, detect-

ing symptoms of faulty operation of the plant, and checking conditions in the compartments or units which are being cooled.

The duties involved in standing a refrigeration watch and in standing an air-conditioning watch are basically the same, since, in both cases, the basic plant is a refrigeration plant. Plants used for air conditioning, however, will include air ducts rather than the refrigerated compartments or spaces associated with refrigeration systems. Until you have learned how to make adjustments to the plant and how to take corrective action when you are standing watch, notify your leading petty officer or the division duty chief whenever adjustments are necessary and whenever abnormal operating conditions occur.

PERIODIC CHECKS.—The interval of time between plant inspections will vary, depending upon the purpose for which the plant is used. The temperatures and pressures throughout the system and the oil level in the compressor crankcase are checked and recorded hourly, unless watchstanding instructions specify otherwise. The results of these checks can be used in determining whether or not the plant is operating properly. One of the best methods for checking the operation of the plant is to compare the existing temperatures and pressures with those which were recorded during a period when the plant was known to be operating properly. It should be noted, however, that this comparison will be valid only if the conditions existing at the time of the two checks were similar.

A sight glass is provided, in the side of the compressor crankcase, for checking the level of the lubricating oil. It is not possible to check the oil level while the compressor is running. The motion of the parts within the crankcase churns the oil and causes foam; as a result, it is impossible to take a reading on the sight glass.

The extent to which the crank ends and the connecting-rod ends are immersed in the oil affect the level of the oil in the crankcase of a compressor. This fact must be taken into account when the oil level is being checked.

As soon as the compressor stops, set the automatic-manual selector switch in the manual position; this will eliminate the possibility of the machine starting while the oil level is being checked. To get an accurate check on the level of the oil, turn the flywheel of the compressor through one revolution and observe the rise and fall of the oil in the sight glass. Record, as the observed oil level, the average height of the oil in the sight glass. Unless otherwise specified, an oil level between the one-fourth and three-fourths positions on the sight glass is satisfactory.

If the oil level is not within the range specified, a decision must be made as to whether the existing situation necessitates securing the compressor or whether the plant may be allowed to continue operating. Unless you have qualified in the procedures to be followed when adding or removing lubricating oil and you are thoroughly familiar with the applicable safety precautions, notify your leading PO or, in his absence, the division duty chief whenever inspection reveals an unusual oil level.

SYMPTOMS OF OPERATING DIFFICULTIES.—You must learn to recognize the symptoms of inefficient operation of the plant so that abnormal conditions can be detected and corrected before they become acute. Faulty operation of a refrigeration system is indicated by various, definite symptoms. These symptoms may indicate one or more abnormal conditions which must first be found, and then be eliminated by specific maintenance or repair procedures. Learning to recognize symptoms of faulty operation of a plant takes time. Some of the symptoms of trouble which you will probably learn to recognize first are: deviations from recommended temperatures and pressures; abnormal lubricating-oil levels; and unusual noises within the compressor. You must, therefore, learn to recognize such symptoms of trouble as abnormal pressures in compressor suction or discharge, lubricating oil, or water supply; excessive temperatures in the liquid line, in the ice-making tank, in compartments, and at the water-overboard discharge or the compressor suction or

discharge; and unusual noises caused by vibration, by hydraulic knocks or worn parts in the compressor, or by water-valve chatter.

OPERATING RECORD.—The operating record of a refrigeration system is maintained by the men on watch. The information recorded serves as a guide for determining how the plant is operating. One page of a typical, daily, operating log for a refrigeration system is shown in figure 17–4.

In addition to furnishing the information shown, a daily operating record must indicate the times at which individual refrigerant-compressors and circulating pumps are started and stopped during the day; the cumulative time during which they have operated during the day; and the cumulative time during which they have operated, to date, during the calendar month. The amount of ice on hand and the amount of ice issued are also recorded.

The headings on the operating log of an air conditioning system are basically the same as those on the refrigeration operating record. The operating data recorded are average readings during the watch, however, rather than the readings obtained at the beginning of each hour.

Securing the Compressor

If a compressor is to be secured for only A SHORT PERIOD, it is not necessary to pump down the system. However, the compressor must be pumped down. To do this, first close the compressor-suction valve slowly, to prevent too rapid a reduction in crankcase pressure. Then, allow the compressor to run until it is stopped by the low-pressure control switch; push the STOP button on the motor-control panel. Next, close the compressor-discharge shut-off valve; shut off the water supply to the condensers. Finally close the main liquid valve after the receiver.

If a refrigeration system is to be secured for AN EXTENDED PERIOD, it must be pumped down. The pumping-down procedure involves pumping most of the Freon-12 out of the coils of the evaporator, and storing the refrigerant in the receiver. This procedure should be em-

COMPRESSOR NO. 2

DATE 2 Feb 1953

TIME	MACH. ROOM TEMP	COMPR SPEED R.P.M. OR %	COMPRESSOR: F-12 SUCTION LBS. GAGE	F-12 SUCTION TEMP. °F	F-12 DISCHARGE LBS. GAGE	F-12 DISCHARGE TEMP °F	OIL LBS GAGE	OIL BULLSEYE LEVEL	CRANKCASE RELATIVE TEMP.	CRANKCASE NOISE	CONDENSER: WATER SUPPLY LBS. GAGE	WATER SUPPLY TEMP °F	WATER O'V'B'D. TEMP °F	F-12 LIQUID: TEMP °F	CONDITION AT SIGHT FLOW	WEATHER: DRY B. TEMP °F	WET B. TEMP °F	REFRIGERATED SPACES: ICE SET TEMP. °F	COMPARTMENT TEMPERATURE °F: Meat RM #1	Thaw RM.	Veg. RM.	Dairy RM.	RM	RM
0100	88	540	7	38	95	162	27	OK	warm	OK	24	60	80	82	OK	82	73	7	17	40	39	32		
0200	89	540	4	46	95	162	25	OK	warm	OK	24	60	82	82	OK	82	73	9	15	38	40	32		
0300	89	540	2	56	95	194	22	OK	warm	OK	24	58	80	86	vapor, bubbles	80	72	11	19	42	42	36		
0400	88	540	3	-4	85	143	24	low	cold	knocks	24	58	80	76	OK	80	70	10	14	40	40	34		
0500	88	540	12	35	95	153	32	low	warm	OK	24	60	80	81	OK	80	69	9	15	40	39	32		
0600	88	540	12	36	96	174	32	OK	warm	OK	[illegible]	58	82	[illegible]							[illegible]	33		
2000	94	540	8	29	106	168	28	OK	warm	OK	24	58	90	92	OK	86	71	7	15	41	40	31		
2100	93	540	10	31	107	165	30	OK	warm	OK	24	58	90	90	OK	84	70.5	9	22	42	39	32		
2200	93	540	10	30	106	162	31	OK	warm	OK	24	58	90	91	OK	84	70	11	23	41	41	33		
2300	93	540	7	30	120	168	28	OK	warm	OK	24	58	90	93	OK	84	70.5	10	18	40	39	32		
2400	93	540	6	30	115	152	26	OK	warm	OK	24	58	90	92	OK	84	71	7	16	39	38	31		

REMARKS: 0300 - Refrigerant shortage - checked and corrected leaky flange at suction line connection to compressor - added 24 lbs Freon-12.
0400 - Expansion valve on #2 coil Meat Room #1 froze in open position flooding refrigerant to compressor - Defrosted valve and connected dehydrator into system.
2000 - 3/8" frost on Meat Room #1 coils - Started defrosting.
2200 - Completed defrosting.

Figure 17—4.—Daily operating log for refrigeration equipment.

ployed whenever the plant is taken out of service for overnight or longer. When a system is to be pumped down, first wedge the low-pressure cutout switch so that the contacts will not open; this prevents the motor from stopping when the pressure drops below the normal setting. Then, close the receiver-outlet valve; the compressor will then draw most of the refrigerant out of the liquid line and out of the evaporator, and discharge it in the receiver. (Where the quantity of liquid refrigerant contained in the system is in excess of the capacity of the receiver, the surplus liquid must be drawn off into the refrigerant drums.) When the suction pressure reaches zero, push the STOP BUTTON on the control panel. Close the suction and discharge stop-valves of the compressor; finally, close the condenser water-supply valves. When restarting the compressor, do not forget to remove the wedge from the low-pressure cutout switch.

It is not good practice to permit any Freon-12 compressor to remain idle for an extended period of time. When two or more compressors are installed in a single refrigerating plant, each compressor should be operated at least once a week. This method of operation is called ALTERNATING OPERATION. All compressors in a plant should be operated for approximately the same amount of time during the service life of the equipment.

Safety Precautions

Many of the precautions which must be observed in the safe operation of an efficient plant have already been pointed out in this chapter. Due to the specific characteristics of Freon-12, however, there are certain additional precautions which should be observed.

HANDLING AND USE OF COMPRESSED-GAS CYLINDERS.—The refrigerant used in shipboard refrigeration systems is furnished in cylinders. When refrigerant cylinders are being handled and used, the following precautions must be observed:

1. Never drop cylinders or permit them to strike each other violently.

2. Never use a lifting magnet or a sling (rope or chain) when handling cylinders. (A crane may be used when a safe cradle or platform is provided to hold the cylinders.)

3. The caps provided for the protection of the valves should always be kept on the cylinders, except when the cylinders are in use.

4. Immediately after refrigerant has been discharged from a cylinder, the cylinder should be weighed; the weight of refrigerant remaining in the cylinder should be recorded.

5. Never attempt to mix gases in a cylinder.

It is essential that no gas other than that for which the particular type of refrigerating machine is designed be introduced into the system. Attempts to use improper gases will, in some cases, result in violent explosions which will either demolish the machine completely or render it inoperative. Freon cylinders are identified with an overall, orange color; check the color of the cylinder to be sure that you are handling and using the correct gas.

6. When a cylinder is emptied, immediately close the cylinder valve to prevent the entrance of air, moisture, or dirt.

As soon as the cylinder is emptied of refrigerant, the valve is closed, and the cylinder disconnected from the system, the protective cap should be placed on the outlet connection of the valve; this will prevent dirt from entering the valve and will also prevent damage to the threads on the valve connection. Check the cylinder caps to be sure that they are in place before the cylinder is placed in storage or returned for recharging.

7. Never use cylinders as rollers or supports, or for any purpose other than to carry gas.

8. Never tamper with the safety devices in the valves or the cylinders.

9. Open the cylinder valves slowly. Never use any wrenches or tools, except those provided or approved by the manufacturer of the gas.

10. Be sure that the threads on the regulators are the same as those on valve outlets on the cylinder. Never force connections that do not fit.

11. Regulators and pressure gages provided for use with a particular gas must not be used on a cylinder which contains another gas.

12. Never attempt to repair or alter either cylinders or valves.

13. Should it become necessary to withdraw Freon-12 from a refrigerating system into cylinders, care should be taken to avoid overcharging the cylinders. Standard, Navy, Freon-12 cylinders should never be filled beyond 80 percent of their capacity: the 20 percent margin provides a space for a cushioning effect when the pressure in the cylinder increases. In this connection, it should be noted that the pressure-temperature relationship of Freon-12 is such that an increase in temperature always results in a corresponding increase in pressure.

STORAGE OF COMPRESSED-GAS CYLINDERS.—The following precautions should be observed when compressed-gas cylinders are being stored or are in storage:

1. Whenever possible, store the cylinders in an upright position, and in a cool, dry place. Cylinders should be stored in a cool place because as the temperature rises, the pressure of the gas in the drums increases correspondingly; this increased pressure may become dangerously high if the temperature reaches a sufficiently high level.

2. Cylinders may be stored in the open; in such cases, however, they should be protected against extremes of weather. During the winter, cylinders which are stored in the open should be protected against the accumulation of ice or snow. In summer, cylinders which are stored in the open should be screened against continuous exposure to the direct rays of sunlight.

3. No part of any cylinder which contains a compressed gas should ever be subjected to a temperature above 125° F. Neither a direct flame nor a jet of steam should ever be permitted to come in contact with any

part of a compressed-gas cylinder. Should it become necessary to warm Freon cylinders to promote more rapid discharge, extreme care must be taken to avoid temperatures above 120° F. The fusible plugs in the cylinder and in the valve of a compressed-gas cylinder melt at about 157° F; they soften at a lower temperature.

4. Never store cylinders near highly flammable substances, such as oil, gasoline, and waste.

5. Cylinders should not be continuously exposed to moisture.

6. To avoid confusion, store full cylinders and empty cylinders in separate places.

7. Do not store full cylinders near elevators or gangways; or in locations where heavy, moving objects may strike them or fall on them.

8. Protect cylinders from any object that will produce a cut or other abrasion in the metal surface of the cylinder.

PERSONNEL PROTECTION AND FIRST AID.—The greatest danger involved in the handling of Freon or in the servicing of refrigeration plants arises from the fact that Freon is such a powerful freezing agent that even a very small amount can freeze the delicate tissues of the eye, causing permanent damage. For this reason, it is essential that goggles be worn by all personnel who may be exposed to Freon, particularly in its liquid form.

If Freon does get in the eyes, the person suffering the injury should receive medical treatment immediately in order to avoid permanent damage to the eyes. In the meantime, put drops of clean olive oil, mineral oil, or other nonirritating oil in the eyes, and make sure that the person does not rub his eyes. CAUTION: Do not use anything except clean, nonirritating oil for this type of eye injury.

If Freon comes in contact with the skin, it may cause frostbite. This injury should be treated as any other case of frostbite. Immerse the affected part in a warm bath

for about 10 minutes, then dry carefully. Do not rub or massage the affected area.

Although Freon is generally classed as nontoxic, it is poisonous in high concentrations such as might occur from excessive Freon leakage in a confined or poorly ventilated space. If a person should be overcome by Freon, remove him immediately to a well-ventilated place and get medical attention at the earliest opportunity. Watch his breathing. If the person is not breathing, give artificial respiration.

Additional information on first-aid treatment for exposure to refrigerants is given in the Navy training course, *Standard First Aid Training Course,* NavPers 10081.

QUIZ

1. What are the principal parts of a refrigeration system through which liquid Freon-12 flows during the operating cycle?
2. Where is the charging connection located in a Freon-12 refrigeration system?
3. How is moisture removed from the liquid side of a Freon-12 system?
4. How can the operator determine the condition of the liquid refrigerant as it flows from the receiver to the cooling coil?
5. What device functions to control the amount of liquid refrigerant that is admitted to the cooling coil?
6. Why are heat exchangers sometimes installed in the compressor-suction line of a refrigeration system?
7. What is indicated on each of the scales of a Freon-12 pressure gage?
8. Will the thermometer in the suction line show a temperature which is higher or lower than that shown on the temperature scale of the suction-line pressure gage?
9. The refrigerant gas which enters the condenser of a Freon-12 system gives up the heat that it absorbed as it passed through what two units of the system?
10. What may be used as a cooling medium in the condenser of a Freon-12 refrigerating plant?
11. What are the possible sources of the circulating water for the condenser of a Freon-12 system?
12. What actuates the valve which controls the quantity of water flowing through the circulating-water line of a Freon-12 condenser?

13. List three troubles which may occur if an air-cooled Freon-12 condenser is not provided with adequate ventilation.
14. Explain briefly the action of the "King" solenoid valve and the result of this action, when the compressor motor is stopped either manually or automatically (by the action of the overload relays or the high-pressure cutout).
15. What causes the automatic functioning of the solenoid stop-valve which is located between the strainer and the expansion valve in the main liquid-line?
16. What is the principal purpose of the suction-pressure control switch (low-pressure cutout)?
17. Where is the high-pressure cutout switch located in a Freon-12 refrigeration system?
18. When will the relief valve in the compressor discharge function?
19. In the event that the condenser circulating-water supply fails and the water-failure switch does not operate, what control functions to stop the compressor?
20. Are the stop valves in the condenser circulating-water lines open or closed when the compressor of a Freon-12 system is started?
21. In what position is the selector switch when a refrigerant compressor is ready to be started?
22. As a refrigerant compressor is being started, when does the "King" solenoid-valve circuit become energized?
23. When a refrigerating system is being placed in operation, why should the compressor be started and stopped several times?
24. What determines the rate at which the suction valve is opened, after the compressor is operating?
25. How is manual control of the condenser circulating-water flow accomplished?
26. What should be done if a refrigerant compressor becomes overloaded, the overload trip fails to function, and overheating occurs?
27. Give two methods by which the tendency of a compressor to short cycle may be decreased.
28. Unless instructions specify otherwise, how frequently should a check be made of the temperatures and pressures in a Freon-12 refrigeration system?
29. Name three general symptoms which indicate that operating difficulties exist in a Freon-12 refrigeration system.
30. What personal protection should be taken when a connection in which Freon-12 may be present is being loosened?

CHAPTER 18

VAPOR COMPRESSION DISTILLING UNITS

As a Fireman, you have been introduced to the need for pure water aboard ship and to some of the equipment used to produce the required amount of water for shipboard uses. More than this introduction will be necessary, however, if you are to meet the requirements for advancement in the Enginemen rating. As an Engineman, you will be required to know how to operate and how to maintain the equipment that provides water aboard ship.

Although the equipment used to distill pure water from sea water varies considerably in design and in installation in different ships, the principle of distillation is the same in all cases. Basically, all distilling units are alike in that sea water is heated to the point of vaporization, the vapor is condensed to make fresh water, and the brine remaining is pumped overboard. The distilling units installed on naval vessels are of two general types: vapor compression, and steam. The main difference between these two types lies in the method of heating the sea water. This chapter deals principally with vapor compression distilling units. Chapter 19 deals with low-pressure steam distilling units.

TERMINOLOGY

The manner in which the various types of equipment accomplish the distilling process will be more easily understood if you are familiar with certain important terms

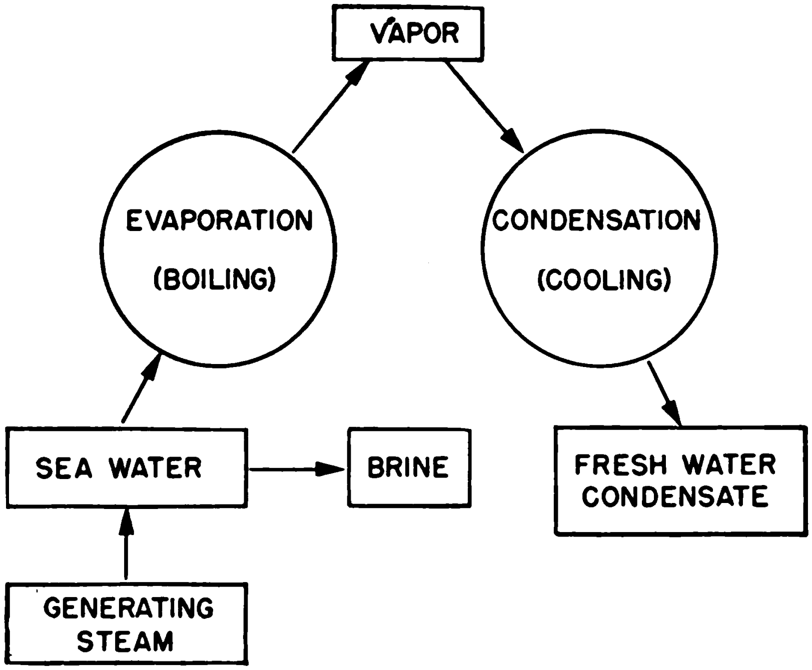


Figure 18–1.—Distillation—Evaporation and Condensation.

related to the process. Refer to figure 18–1 as you study the following definitions.

DISTILLATION.—The process of boiling sea water and then cooling and condensing the vapor to produce fresh water from salt water.

EVAPORATION.—The first half of distillation, this is the process of boiling sea water to divide it into fresh water vapor and brine. The term "evaporator" is derived from this process.

CONDENSATION.—The second half of distillation, this is the process of cooling fresh-water vapor to condense it to usable fresh water.

VAPOR.—The product of evaporation. The terms "vapor" and "fresh water vapor" are used interchangeably in connection with shipboard distilling plants.

CONDENSATE (DISTILLATE).—The product resulting from the condensation of the fresh water vapor produced by evaporating sea water. The terms "fresh water," "condensate," "fresh-water condensate," and "distillate" mean the same thing.

SALINITY.—The concentration of salt in water.

BRINE.—Water which has a higher concentration of salt than sea water.

DISTILLING UNIT.—A system of heat exchangers, pumps, and piping, which, working as a unit, produces fresh water from sea water.

DISTILLING PLANT.—The complete distilling installation on board ship, comprising one or more individual distilling units.

TYPES OF VAPOR COMPRESSION DISTILLING UNITS

The vapor compression type distilling unit was first developed for submarine service, where the absence of a steam supply necessitated some other source of heat for the evaporating process. These units require electrical energy for their operation. They are now used on small Diesel-driven surface craft, and on vessels with daily requirements which do not exceed 4,000 gallons.

There are two general types of vapor compression units in use on naval ships. The two types of units differ principally in the type, location, and function of the heat exchanger. (Compare figs. 18–2 and 18–4.)

Model S

The first vapor compression unit was the Model S, built in only one size, and having a capacity of 750 gallons per day (gpd). A schematic view of the Model S distilling unit is shown in figure 18–2.

The Model S unit has a coil-type heat exchanger, located within the evaporator shell. Electric heaters cause the sea-water feed to boil and vaporize. The vapor flows through the compressor and into the submerged coil. In passing through the upper turns of the coil, the vapor heats the sea water and causes additional vaporization within the evaporator shell. In the process of giving off heat, the vapor condenses and flows downward through the coil. The relatively hot condensate gives off heat to the relatively cold sea water which is entering the evaporator

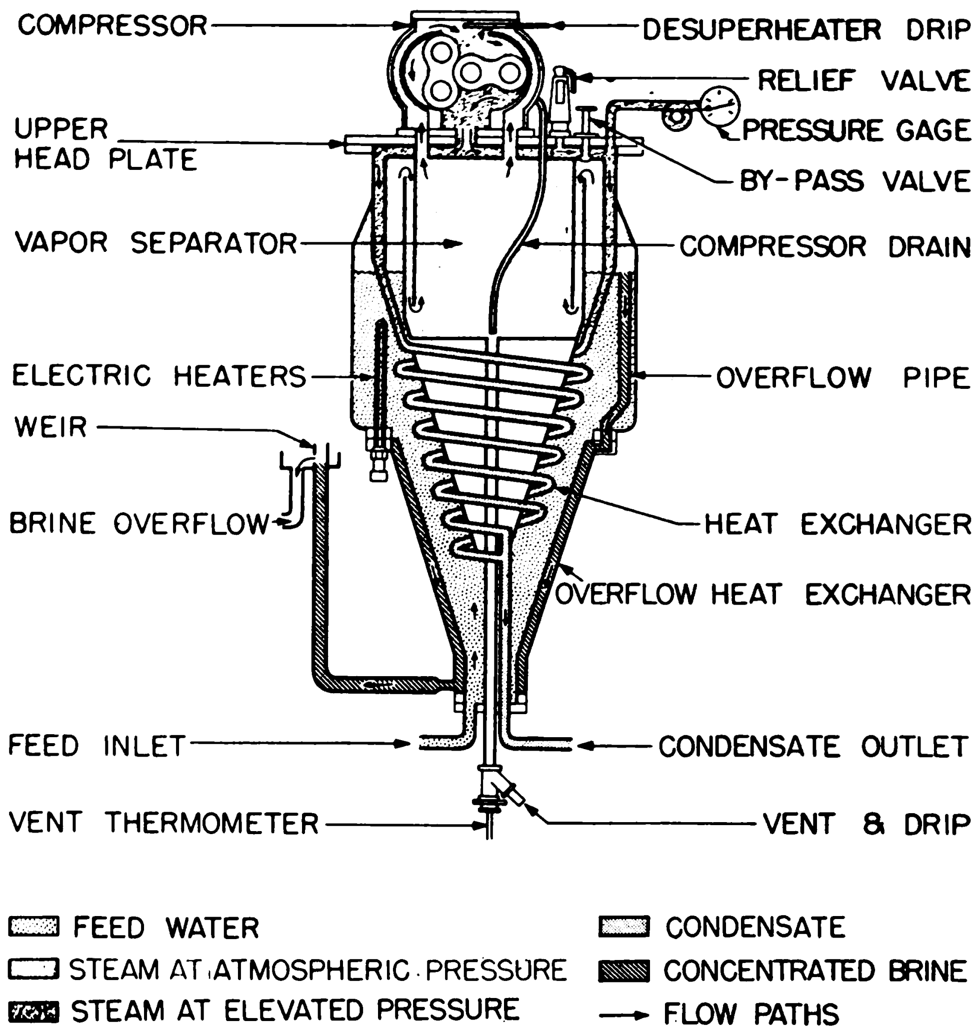


Figure 18–2.—Model S vapor compression distilling unit.

at the bottom of the shell. Thus, the coil (heat exchanger) serves to heat and vaporize sea water, to condense the resultant vapor, and to cool the condensate.

Model X

Models of vapor compression units subsequent to the Model S include radical design changes. The first of these newer models is the Model X. This model is built in two sizes, 1,000 gpd (Model X–1) and 2,000 gpd (Model X–2). Many of the original Model S units have been replaced by Model X–1 units.

In the Model X, the vaporizing and condensing of the

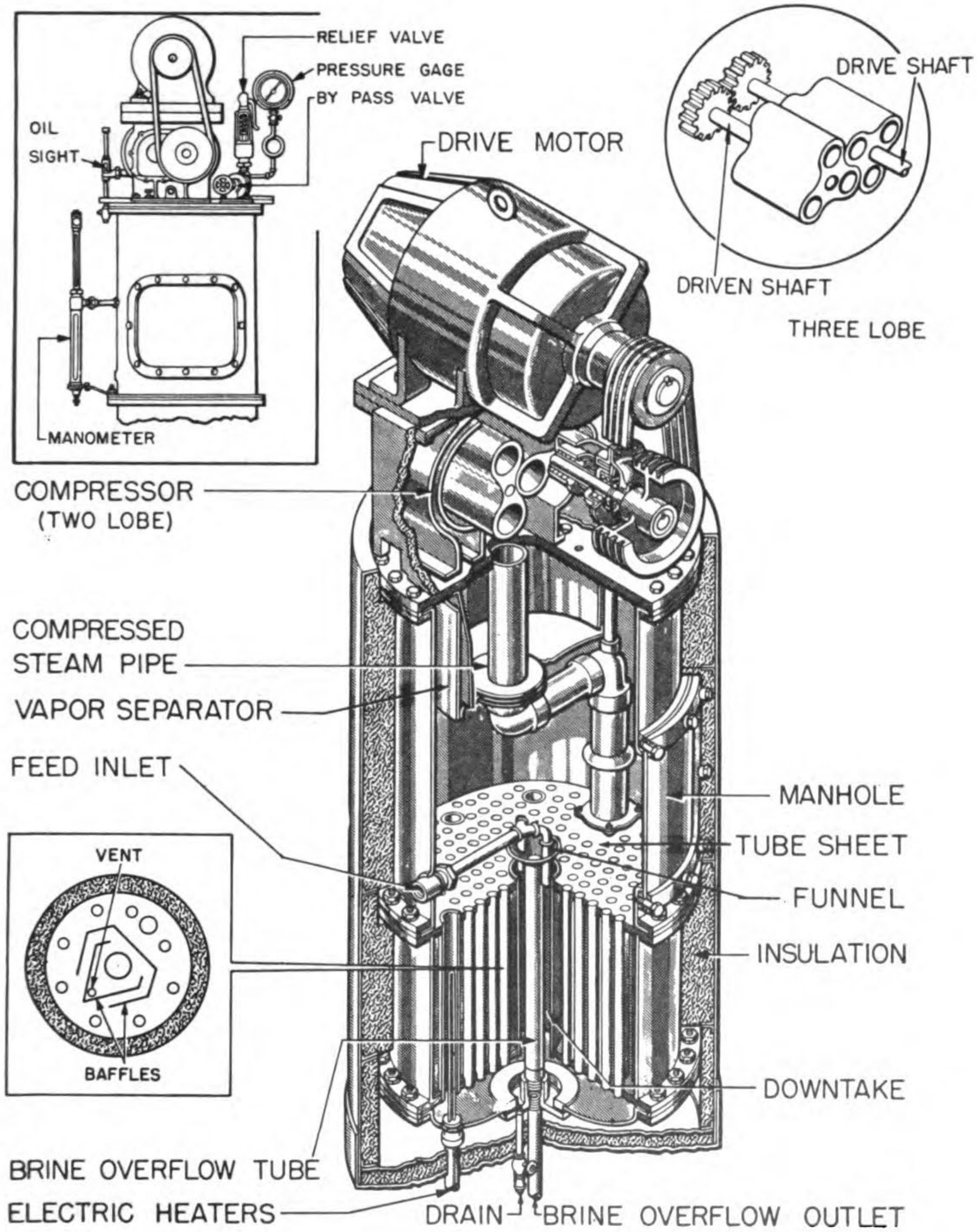


Figure 18–3.—Model X–1 vapor compression distilling unit.

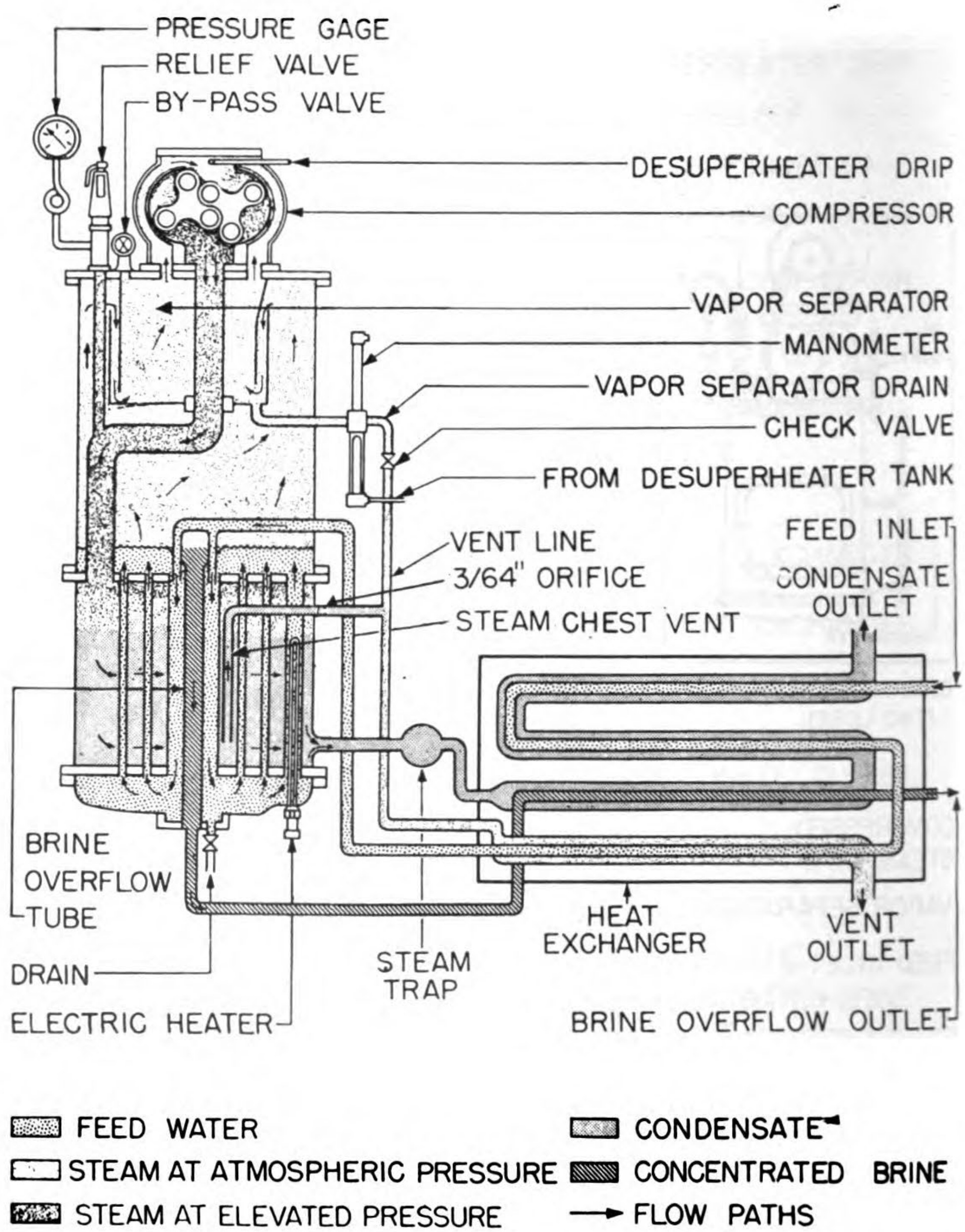


Figure 18–4.—Model X–1 distilling unit with heat exchanger.

feed is accomplished in the evaporator; the warming of the feed and the cooling of the condensate, however, are accomplished in an external heat-exchanger of the double-tube type (tube within a tube). Cutaway and schematic views of the Model X–1 distilling unit are shown in figures 18–3 and 18–4, respectively.

New Models

Still more recent developments in vapor compression units include Models V–1 and the Y–1, each of which has the same rated capacity as the Model X–1 unit. Two smaller models (300 gpd capacity) are also in use. These smaller units are similar to the Model X–1, but are far more compact. All of these vapor compression units have external heat-exchangers.

DESCRIPTION OF THE MODEL X–1 UNIT

It is beyond the scope of this course to describe all of the various, vapor compression, distilling units in detail. Since all these units operate on the same basic principles, however, the Model X–1 is described here as an example of vapor compression units. Refer frequently to figures 18–3 and 18–4 as you study the following information dealing with the construction and operation of the Model X–1.

The Model X–1 vapor compression unit will produce 50 to 60 gallons of distilled water per hour from 70 to 90 gallons per hour of normal sea water. The Model X–1 consists of three main components: the evaporator, the compressor, and the heat exchanger.

Evaporator

The unit in which the vaporization and condensation take place is commonly called the evaporator. The evaporator is cylindrical in shape, and is provided with a manhole-opening. The cylindrical shell is covered with a thick layer of glass-wool insulation, which is held in place by a stainless-steel jacket. (See fig. 18–3.)

The evaporator can be subdivided into two principal elements: the steam chest; and the vapor separator.

STEAM CHEST.—For the purpose of this discussion, the steam chest is considered to include all the space within the evaporator shell, except that space occupied by the vapor separator. The steam chest is also considered as

having two sides: the evaporating side; and the condensing side. The evaporating side includes the space within the tubes of the tube bundle, which is located in the lower part of the evaporator shell; and the space which communicates with the inside of the tubes. The condensing side includes the space which surrounds the external surfaces of the tubes. This space communicates with the discharge side of the compressor by means of a pipe. (See fig. 18–4.)

The principal element within the steam chest is the tube bundle. The bundle consists of 334 ¾-inch OD tubes and eight 1¾-inch tubes. The tubes are 16¼ inches long. The smaller tubes are set side by side; the larger tubes, located near the periphery of the tube-bundle, are spaced an equal distance apart. (See fig. 18–3.) The tube bundle is enclosed in a shell; at the top and bottom of the shell, the ends of the tubes are expanded into the tube sheets.

Two, angular, sheet-brass BAFFLES, 14¼ inches high, are located among the tubes on the condensing side. (See inset, fig. 18–3.) A pipe, called a STEAM CHEST VENT, leads horizontally into the condensing side of the tube nest at a point about 2½ inches below the top tube-sheet (fig. 18–4). The vent bends down into the corner of the inner baffle (see inset, fig. 18–3) extending to 2 inches from the bottom tube sheet. This section of pipe is pierced with nineteen 1/16-inch holes, in two rows; the holes are staggered and are on the side of the pipe which is toward the open part of the baffle. Any noncondensable gases, such as air, flow to the closed end of the inner baffle; from there, the gases pass out through the steam chest vent.

A 100-mesh STRAINER and an ORIFICE PLATE are located within the steam chest vent, just outside the evaporator shell. The purpose of the orifice plate is to vent air from the condensing side of the steam chest. Normally, only a very small amount of air is present here; hence, the orifice in the orifice plate is small. The orifice plate prevents drainage from the vapor separator drain pipe

and the manometer from entering the distilled water, through the steam chest vent.

Each of the eight 1¾-inch tubes contains an ELECTRIC HEATER. As the feed flows through these tubes it comes in contact with the heaters, which brings the feed up to the boiling point. (See figs. 18–3 and 18–4.)

Each of the heaters is a 666-watt, 125-volt, special chromalox, immersion-type heater, of hairpin design. Each heater measures 17⅝ inches, over-all, in length; has an immersion length of 14 inches; and has an active heating length of 12⅝ inches. Two heaters are wired, in series, to each switch; thus, four heater switches are required.

The FEED INLET PIPE extends horizontally to the center of the evaporator; there it branches into a Y, the two ends of which turn down and extend to a level just below the FUNNEL (fig. 18–3). The ends of the Y actually pass through the wall of the funnel. The incoming feed pours into the downtake, and mixes with the feed already in the evaporating side.

In the center of the tube bundle is a 4-inch pipe, the ends of which are expanded into the tube sheets. This pipe is called the DOWNTAKE. The feed enters the evaporator, through a pipe above the tube bundle; passes down, through the downtake to the bottom head of the evaporator shell; and then flows up through the tubes. (See figs. 18–3 and 18–4.)

The funnel is brazed to the top of the 1¾-inch OD BRINE OVERFLOW PIPE (fig. 18–4), which is installed inside the downtake. The top of the funnel is 2 inches above the top of the evaporator tubes; the brine level in the evaporator shell is, therefore, maintained at this height. About one-half to two-thirds of the feed is vaporized; the remaining brine overflows continuously into the funnel and the overflow pipe. The overflow pipe leads the brine out, through the bottom of the evaporator shell, to the heat exchanger; here the brine gives up its heat, raising the temperature of the incoming feed.

VAPOR SEPARATOR (see figs. 18–3 and 18–4).—An internal compartment located at the top of the evaporator shell is referred to as the vapor separator. The separator consists of two cylindrical baffles. One cylinder extends downward from the upper head plate of the evaporator; the other extends upward, and fits around the upper cylinder in a baffle arrangement. The floor of the separator is formed by the bottom of the outer cylinder. The space between the two cylinders provides a passage for the vapor flowing from the evaporator side of the steam chest to the suction side of the compressor.

The vapor from the boiling sea water rises up through the space between the shell wall and the outer cylinder of the separator; it then flows downward, through the space between the cylinders of the vapor separator, and enters the separator chamber. The vapor then travels upward, from the separator chamber to the intake, or suction, side of the compressor.

In the course of this roundabout passage through the vapor separator any particles of water carried up with the vapor separate from it and drop to the floor of the separator. Since the water that is separated from the vapor has a high concentration of salt, it is necessary to drain this salt water from the separator continuously. Otherwise, the water would enter the compressor (and, consequently, the condensing side of the steam chest) and contaminate the fresh water. In some Model X–1 units, the separated water drains out of the separator through the separator drain pipe, the manometer, and a check valve into the evaporator vent pipe, and then through the heat exchanger into the bilges. Some units have been modified so that the drain from the separator collects in an evaporator seal cup inside the unit, and overflows through the brine-overflow pipe. In these modified units, a compound pressure gage and a pressure-controlled switch are used in place of a manometer. (These instruments will be discussed later.)

Vapor Compressor

The vapor which flows upward from the separator of a Model X–1 distilling unit is compressed by a positive-displacement compressor. (See fig. 18–3.) The Model X–1 may be equipped with a Type XB–1 compressor or a Model AAA–1 compressor. The latter is a refinement of the XB model. Both compressors have the same basic design; the Model AAA–1 has two 3-lobe spiral rotors, however, while the XB–1 unit has two 2-lobe straight rotors. A description of the Model AAA–1 compressor follows.

COMPRESSOR COMPONENTS.—This compressor consists of two ROTORS enclosed in a compact HOUSING which is designed to be mounted on the evaporator.

Each rotor has three helical lobes which are designed to produce a continuous and uniform flow of vapor. The vapor enters the compressor housing at the bottom (fig. 18–4); it then passes upward, between the inner and outer walls of the housing, to the rotor chamber, where it fills the spaces between the rotor lobes. The vapor is then carried around the cylindrical sides of the housing, and a pressure is produced at the bottom as the lobes roll together. Clearance is provided to prevent the rotors from touching either each other or the surrounding housing.

The shaft of one rotor is fitted with a drive pulley on one end and a helical gear on the other. The gear meshes with a gear on the shaft of the other rotor to provide the necessary drive for the second rotor. (See fig. 18–3.) The IMPELLER GEARS run in an oil bath, in an oiltight housing. The shafts pass through packing glands in the housing.

COMPRESSOR MOTOR AND DRIVE.—An electric motor ($7\frac{1}{2}$-hp), with the necessary starting and protective (electrical) equipment, is bolted on top of the compressor casing (fig. 18–3). The compressor drive consists of a variable-pitch sheave on the motor; a set of four, matched V-belts; and a solid sheave on the compressor drive shaft. The variable-pitch sheave is provided primarily to furnish

a means of maintaining proper belt tension. The proper tension is that which gives the belt a bow of about an inch on the slack side, when the unit is operating.

COMPRESSOR LUBRICATION.—The compressor is lubricated from two oil reservoirs, one at each end. Each reservoir is supplied with an oil-level indicator, which is attached to the compressor housing.

The reservoir of oil at the drive end of the compressor lubricates the thrust bearings by slinger rings. The reservoir at the gear end provides direct splash lubrication for the gears and bearings. Stuffing-box glands prevent steam leakage into the oil reservoirs. The glands should be adjusted so that they will be just tight enough to prevent leakage. Excessive tightness will damage the packing and the shaft sleeves; this will result in excessive heating and will cause the impellers to stick. The gland nuts must be tightened evenly.

Heat Exchanger

The heat-exchanger is a preheater which warms the incoming sea-water feed by removing heat from the condensate before it goes to the ship's tanks; and by removing heat from the brine overflow before it is discharged overboard or to the brine-collecting tank. The construction of the heat exchanger and a diagram of the flow paths (feed, overflow, condensate, vent) through the exchanger are shown in figure 18–5. (Also see Flow Paths, fig. 18–4.)

CONSTRUCTION.—The heat exchanger is of the horizontal, double-tube type; it is so arranged that either sea water or brine flows through the inner tubes, while condensate flows through the space between the inner and the outer tubes. This arrangement simplifies the cleaning process, since any scale from the sea water or the brine is deposited inside the inner tubes; when the end covers are removed, these tubes are readily accessible for cleaning. The distilled water, on the outside of these tubes, contains no scale-forming chemicals or salts.

In the most modern heat exchangers used with the

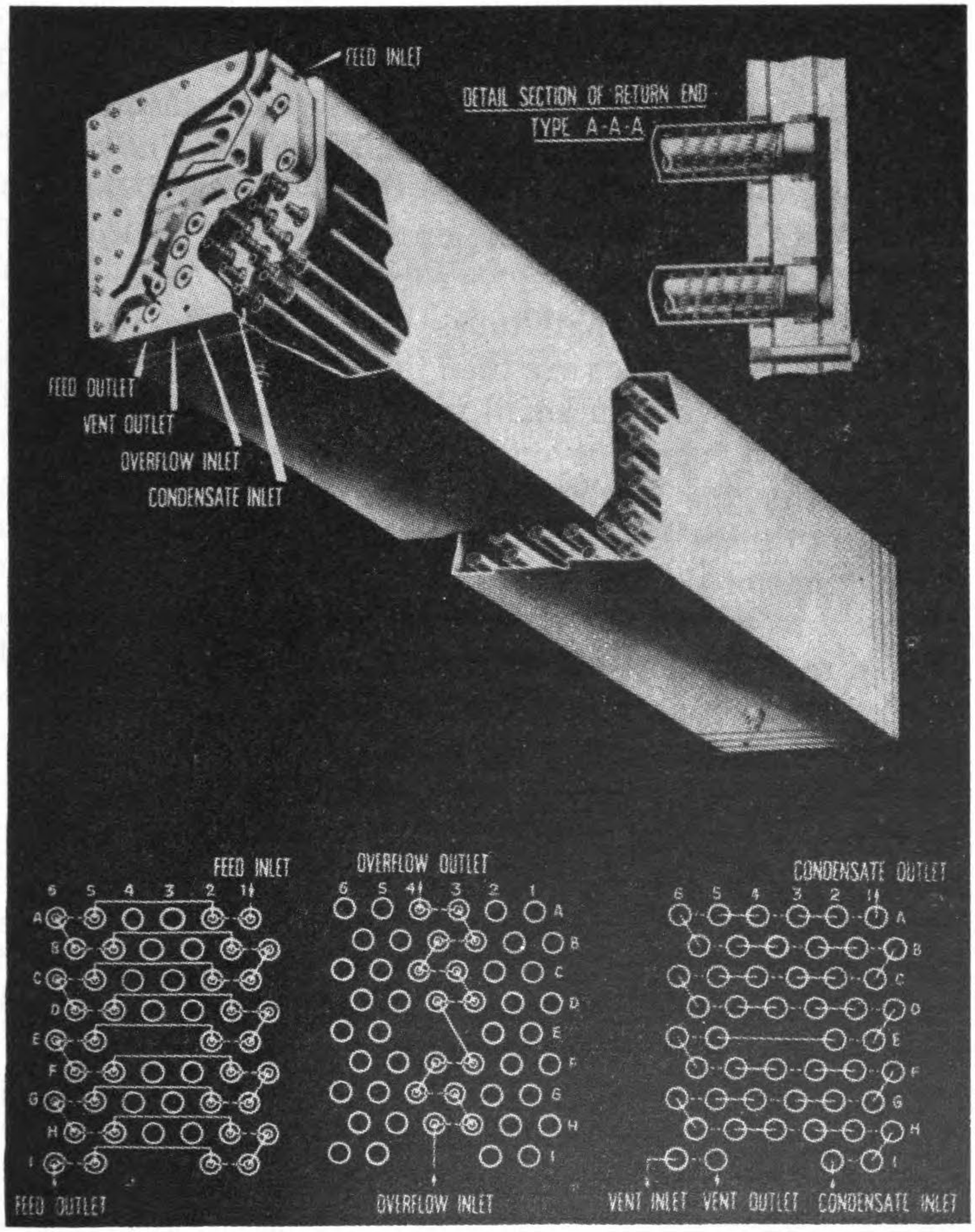


Figure 18–5.—Heat exchanger and flow paths.

Model X–1, there is an inner tube within each of fifty outer tubes. The tubes are of straight construction; each outer tube has an inside diameter of 1¼ inches, and is 45 inches long. The inner tubes are ¾ inch OD, and 48 inches long. The ¾-inch tubes are externally finned, with copper-nickel wire. (See detailed section, fig. 18–5.) There are six tube sheets, three on each end of the assembly.

The large tubes of the heat exchanger are arranged in a bank and are inserted in the inner-tube sheets (fig. 18–5); the tubes are packed into these tube sheets with fiber and metallic packing to prevent leakage. The metallic packing should be installed so that it does not come in contact with the fresh water, or condensate, side of the heat exchanger.

The ends of the small tubes are silver-soldered into bushings, and the tubes are then inserted inside the larger tubes. The ends of the small tubes (with bushings) extend about $1\frac{1}{2}$ inches beyond the ends of the larger tubes, and through the outer-tube sheets. The bushings are packed into these tube sheets. The tube-sheet cover-plates seal the ends of the heat exchanger. The outer-tube sheets and the tube-sheet cover-plates contain milled passages which direct the flow of water. The entire tube bundle is enclosed in a brass casing for protection.

FLOW PATHS.—In the heat exchanger, there are four, distinct, flow paths: FEED, BRINE OVERFLOW, CONDENSATE, and VENT. (See figs. 18–4 and 18–5.) The condensate flows through 48 large tubes, which surround the smaller tubes. Steam from the vent pipe and drainage from the vapor separator flow through two large tubes which surround smaller tubes. Feed water flows through 36 of the small tubes. The brine-overflow from the evaporator side flows through 14 of the small tubes. The tubes in each flow path are connected, by return headers, in such a way as to provide a flow path which is completely separate from the other three paths.

The diagrams in the lower portion of figure 18–5 show these four, separate, flow paths. These diagrams show the pipes as viewed from the inlet-outlet end; and as viewed by a person looking toward the rear, or return, end. In order that the flow paths may be described readily, the tubes are designated in accordance with the following plan.

The rows are designated by letters, starting with the top row. Capital letters refer to the large tubes; small

letters refer to the $\frac{3}{4}$-inch OD tubes. The tubes in each row are designated by numbers 1 to 6, starting at the right. In the diagram, only the top row shows the numbers; the rows below it are similarly designated, however. In the following description, the term "goes forward" means that the flow is away from the observer as he looks at the flow diagrams in figure 18–5; that is, away from the inlet-outlet end and toward the return end. The term "comes back" means that the flow is in the opposite direction; that is, toward the observer, or from the return end to the inlet-outlet end. When it is said that the flow goes forward in a–1 and comes back in a–2, it is understood that the flow crosses from a–1 to a–2 in the return-end header. When it is said that the flow comes back in a–2 and goes forward in a–5, it is understood that the flow crosses from a–2 to a–5 in the header at the inlet-outlet end.

The cold sea-water feed enters the heat exchanger at the top. (See feed inlet, fig. 18–5, and the FEED FLOW diagram.) The feed flows through 36 small tubes. The feed goes forward in a–1, comes back in a–2, goes forward in a–5, comes back in a–6, goes forward in b–6, comes back in b–5, goes forward in b–2, and comes back in b–1. The feed follows the same route in rows c, d, e, f, g, h, and i, and emerges hot from tube i–6 at the feed outlet. (See fig. 18–5.)

The hot brine-overflow uses the remaining 14 small tubes; the hot brine enters the heat exchanger at the bottom. (See OVERFLOW PATH diagram, fig. 18–5.) It goes forward in h–4, comes back in h–3, goes forward in g–3, and comes back in g–4. Continuing, the brine follows the same route in rows f, e, c, b, and a, and emerges cool from tube a–4, at the brine-overflow outlet. (See fig. 18–5.)

Forty-eight of the large-diameter tubes serve as the path for the CONDENSATE FLOW. The hot condensate enters the heat exchanger at the bottom. It goes forward in I–2, comes back in I–1, goes forward in H–1, comes back in H–2, goes forward in H–3, comes back in H–4, goes for-

ward in H–5, comes back in H–6, goes forward in G–6, comes back in G–5, goes forward in G–4, comes back in G–3, goes forward in G–2, comes back in G–1, and goes forward in F–1. Continuing, it follows the same route, as may be seen in figure 18–5, through the remaining rows. The condensate emerges cool from tube A–1 at the condensate outlet.

Noncondensable gases from the manometer and from the steam chest flow through the remaining two large tubes in the bottom row; here the steam is condensed and the gases are cooled. (See diagram of VENT FLOW, fig. 18–5.) The gases enter hot and go forward in I–6; they come back in I–5, and emerge, somewhat cooled, from tube I–5 at the vent outlet.

It may be noted that the heat transfer in the heat exchanger takes place on a step-by-step basis. The hot condensate gives up some heat to the feed in tubes I–2, I–1, H–1, and H–2; it picks up a little heat from the overflow in G–4, and G–3; it gives up heat to feed in G–2, G–1, F–1, and F–2; and it continues this step-by-step heat transfer throughout its path to A–1.

The sea water enters the heat exchanger at ocean temperature, which varies according to location and season. The feed, after absorbing heat from the condensate and brine-overflow, leaves the heat exchanger at about 200°F. Therefore, the temperature of the feed needs to be raised only a few degrees in the evaporator tubes in order to reach the boiling point. The distilled water, or condensate, leaving the steam chest reenters the heat exchanger, at about the same temperature as that of the condensing steam in the steam chest (220°F at 3 psi); and it passes counter-current to the feed flow (that is, opposite to the flow). These conditions ensure the maximum heat transfer from the hot, outgoing, distilled water to the cool, incoming feed; the feed is warmed and the distillate, or condensate, is cooled as a result of the heat transfer.

Accessories and Auxiliaries

Numerous accessories and auxiliaries are essential if a vapor compression distilling unit is to perform its function efficiently. Pumps are required in the feed, condensate, and brine-overflow circuits. Various types of valves and control devices are also part of the complete distilling unit. The relative location of some of these accessories and auxiliaries is shown in figures 18–3 and 18–4. Three of the control devices are illustrated in figures 18–6, 18–7, and 18–8.

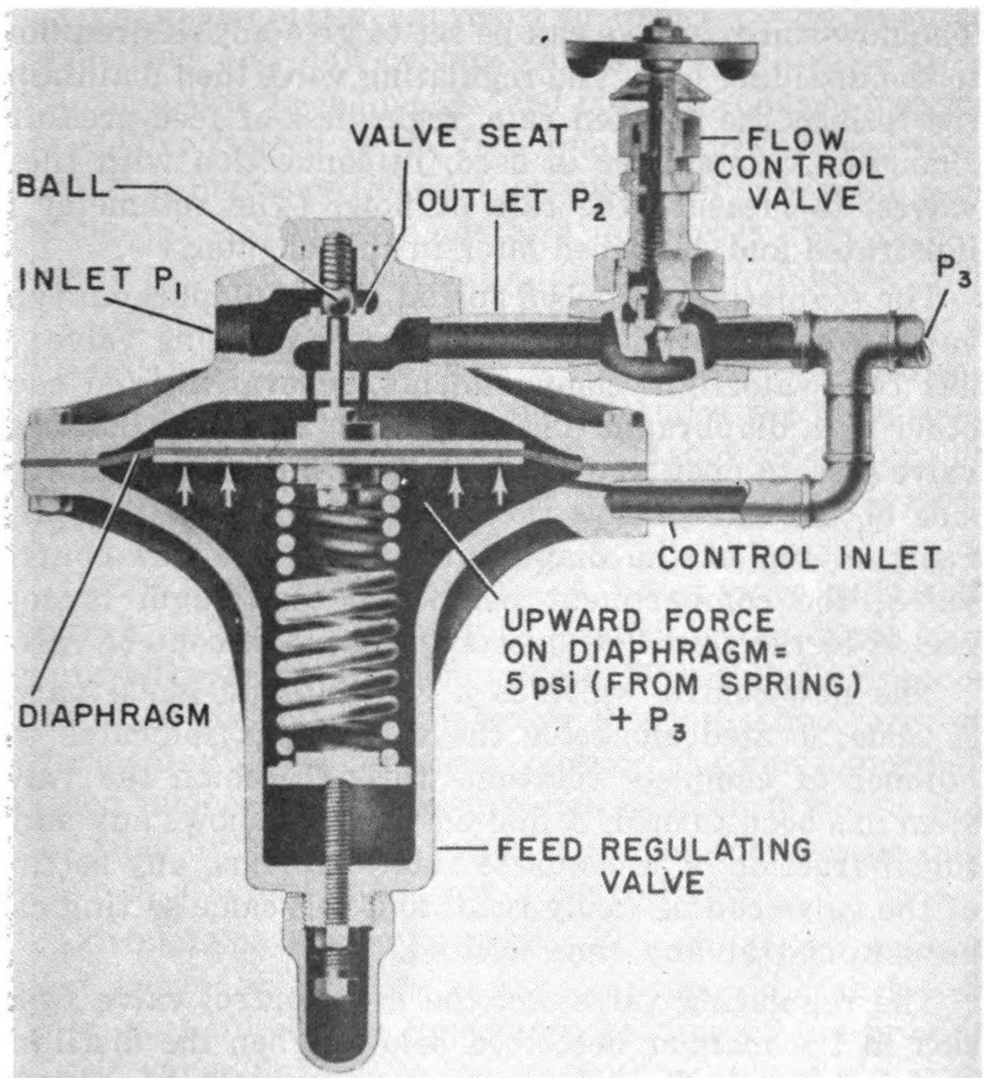


Figure 18–6.—Feed regulating and flow control valves.

FEED PUMP.—The main sea-water supply for the Model X–1 unit is delivered by a small centrifugal pump, which is direct-connected to the driving motor. The pump has a capacity of 3 to 4 gallons per minute, at 30 to 40 pounds gage pressure (psig). The capacity of one of these pumps is great enough to supply two model X–1 units; only one feed pump, therefore, is supplied for installations with one or two distilling units.

FEED REGULATING AND FLOW CONTROL VALVES.—In the feed line, just beyond the water filters, are the feed-regulating valve and the feed- or flow-control valve (fig. 18–6). These valves control the flow of the incoming feed-water. The flow-control valve can be set to give any desired flow to the distilling unit. The regulating valve then maintains the feed at the selected rate, regardless of feed-pressure changes. A rotameter is used, in connection with these valves, to measure the rate of flow. (The rotameter is illustrated and described later in this chapter.)

The regulating valve is a spring-loaded diaphragm-type valve, which is similar to an ordinary reducing valve; it has two watertight compartments, separated from each other by a diaphragm. The diaphragm acts on a ball-type valve disk to open and close the feed line. The discharge side of the valve, below the ball, is open to the compartment on top of the diaphragm and to the flow-control valve; the compartment below the diaphragm is connected to the feed line, just after the flow-control valve.

The flow-control valve is a conventional globe valve. A scale, located alongside the valve stem, indicates the number of complete rotations through which the valve stem has been turned. A dial on the stem shows any additional fraction of a complete rotation. Thus, any setting of the valve can be easily read; and this same setting can be obtained at any time desired.

The regulating valve and the flow control valve function in the manner described below. When the distilling unit is in operation, the water pressure (P_2, fig. 18–6) just before the flow-control valve is exerted downward

on the diaphragm of the regulating valve. The coil spring in the lower compartment of the regulating valve exerts on the diaphragm an upward pressure which is 5 psi in addition to the pressure (P_3, fig. 18–6) in the feed line just after the flow-control valve. Thus, the pressure (P_2, fig. 18–6) in the feed line just before the flow-control valve will always be exactly 5 psi more than the pressure in the feed line just after the flow-control valve. Once the flow-control valve is set at any given opening, the flow through it will remain constant, regardless of pressure fluctuations in the feed line before the regulating valve or after the flow-control valve.

OTHER FEED-LINE VALVES AND DEVICES.—Between the regulating and flow-control valves, a relief valve is installed in the feed line. A feed-pump discharge-pressure gage is connected to the feed line beyond the feed-water filters; it indicates the feed pressure just before the regulating valve. The feed line also includes a stop valve, a strainer, filters, a relief valve, and a feed rotameter.

COMPRESSOR BYPASS VALVE.—This valve is located on top of the upper head-plate of the Model X–1 unit. It is a stop valve which, when open, permits the compressor discharge to return directly to the vapor separator. The valve is open when the plant is being started; it is closed when the plant is in operation.

COMPRESSOR RELIEF VALVE.—A relief valve, which discharges to the atmosphere, is located on the upper head-plate adjacent to the compressor. This relief valve, connected to the vapor compressor discharge line, prevents overloading the compressor motor. The valve, normally closed under spring pressure, can be opened manually at any time by lifting the valve lever. The compressor relief valve is a safety valve, not a control valve.

COMPRESSOR PRESSURE GAGE.—A 0- to 15-psi pressure gage is connected in the vapor compressor discharge line. This gage provides a continuous reading of the pressure of the vapor flowing to the condensing side of the steam chest.

CONDENSATE STEAM TRAP.—The condensate leaving the condenser section of the evaporator passes through a steam trap. The purpose of this steam trap is to permit the condensate to flow from the steam chest and at the same time to prevent the loss of steam from the condensing section. In so doing, the trap functions to allow the extraction of latent heat from all steam formed in the evaporator and delivered to the condensing side of the steam chest. It is also true that if the steam flowed freely from the steam chest, compression would not be possible; hence there would be no increase in the temperature of the steam.

The steam trap is of the mechanical type. A trap of this type is illustrated in *Fireman,* NavPers 10520-A. The condensate enters the trap horizontally at one side; it leaves the trap at a point diametrically opposite. Normally, the steam trap is about half full of condensate. A spherical float, connected by a lever to a pin-valve in the outlet, rises and falls with the condensate level, permitting condensate to flow out only as fast as condensate flows into the trap.

The steam trap functions in the manner described below. The condensate leaving the steam chest has some uncondensed steam mixed with it. In the steam trap, the condensate fills only the lower half of the enclosed space; the upper half is steam space. When the condensate drops below this normal level the float drops with it, shutting the outlet valve. The outlet valve remains shut until the water level rises again to normal position. There is a permanent bypass, around the valve of the steam trap, from the vapor chamber to the outlet pipe. This bypass serves to prevent the trap from becoming air-bound. (When the compressor bypass valve is open, air is discharged through the trap.) If the permanent bypass is clogged, the trap must be vented manually before the unit can operate. On the top of the trap there is a small valve, which can be opened manually to vent off large quantities of air.

The condensate normally flows from the steam chest as rapidly as it is formed. When the flow of condensate is restricted, pressure will build up in the steam chest. Restriction of the condensate-flow may be caused by the float being stuck in the closed position, or by the orifice in the bypass being plugged. When the condensate-flow is restricted, vent air from the steam trap, by hand; if the pressure in the steam chest comes down and then gradually builds up again, the trap is, in all probability, not operating properly. The unit should then be secured and the steam trap repaired.

CONDENSATE PUMP.—A centrifugal-type, motor-driven, condensate pump, having a capacity of 4 gallons per minute, takes suction, through the condensate trap, from the vapor space of the steam chest; it discharges, through the heat exchanger, to the test tank. One pump is required for each unit except on submarines, where the units are arranged to permit gravity flow, through the heat exchanger, to the test tank.

ROTAMETERS.—Two of these devices are provided with each distilling unit. One, inserted in the incoming sea-water line to the heat exchanger, measures the rate of the feed flow (normally, 70 to 90 gph). The other, in the brine-outlet pipe from the heat exchanger, measures the rate of brine-overflow (approximately $\frac{1}{3}$ to $\frac{1}{2}$ of the total feed). Two views of a rotameter and a schematic diagram of the flow through the device are shown in figure 18–7.

The rotameter is basically an upright pyrex-glass tube, about 14 inches long (exclusive of end-fittings), through which the water flows. A metal casing, fitted with a plexiglas window, protects the glass tube. This tube is tapered, with the small end at the bottom. A rod, supported by the end fittings, is centered in the tube. A rotor rides freely on this rod. Since the tube is tapered, the area for flow between the rotor and the tube is increased as the rotor rises on the rod; an increased flow through the tube is indicated by the rising rotor. A scale on the

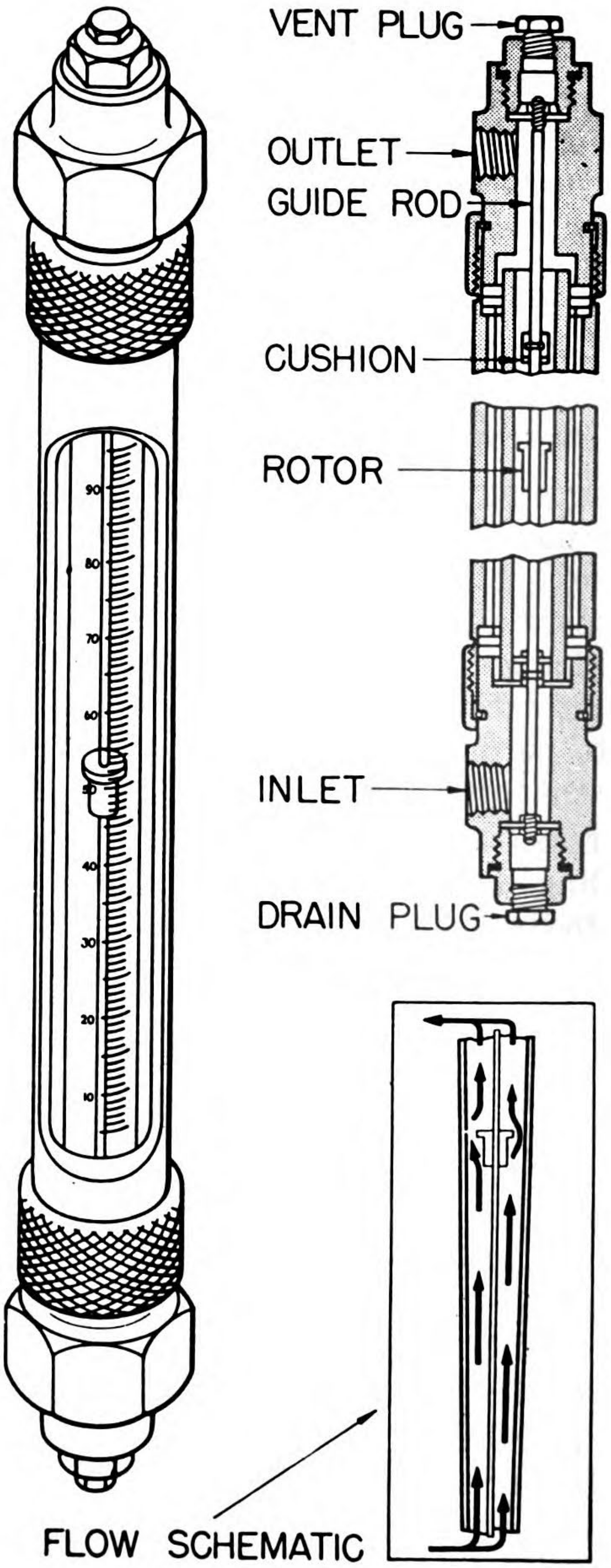


Figure 18–7.—Rotameter.

tube is calibrated so that the flow may be read directly; the reading is taken at the top of the rotor.

MANOMETER.—This device is installed in the vapor separator drain, which leads to the evaporator-vent pipe. (See fig. 18–4.) The manometer is an instrument which indicates the pressure of the steam in the vapor separator. The basic principles of the manometer are given in *Fireman,* NavPers 10520–A. Two views of a manometer, of the type used on the Model X–1, are shown in figure 18–8.

The manometer consists essentially of a brass framework holding two glass tubes, one within the other. The inner tube is approximately twice as long as the outer tube. The outer tube is closed at the bottom; at the top it has two openings, one of which is connected to the drain from the vapor separator, while the other is the manometer drain to the heat exchanger. The inner tube is open at both ends. The lower end of the smaller tube is inside the larger tube, near the bottom of that tube; the upper end, projecting out of the top of the larger tube, is open to the atmosphere.

When the distilling unit is in operation the outer tube of the manometer receives a small amount of water, normally supplied by drainage from the vapor separator. During the warming-up period, some water is drawn out of the manometer and into the vapor separator. Just before the distilling unit is cut in, the manometer should be filled to its normal operating level (at the top of the outer glass tube) with water from the desuperheater tank. (A pipe connection and valve are provided, near the bottom of the manometer, for this purpose.) While the distilling unit is in operation, the upper surface of the water in the outer glass tube is subjected to pressure from the vapor separator. This pressure may be either above or below atmospheric pressure. Since the upper end of the inner glass tube is open, the water in the inner tube is subjected to two forces: the vapor pressure caused by the

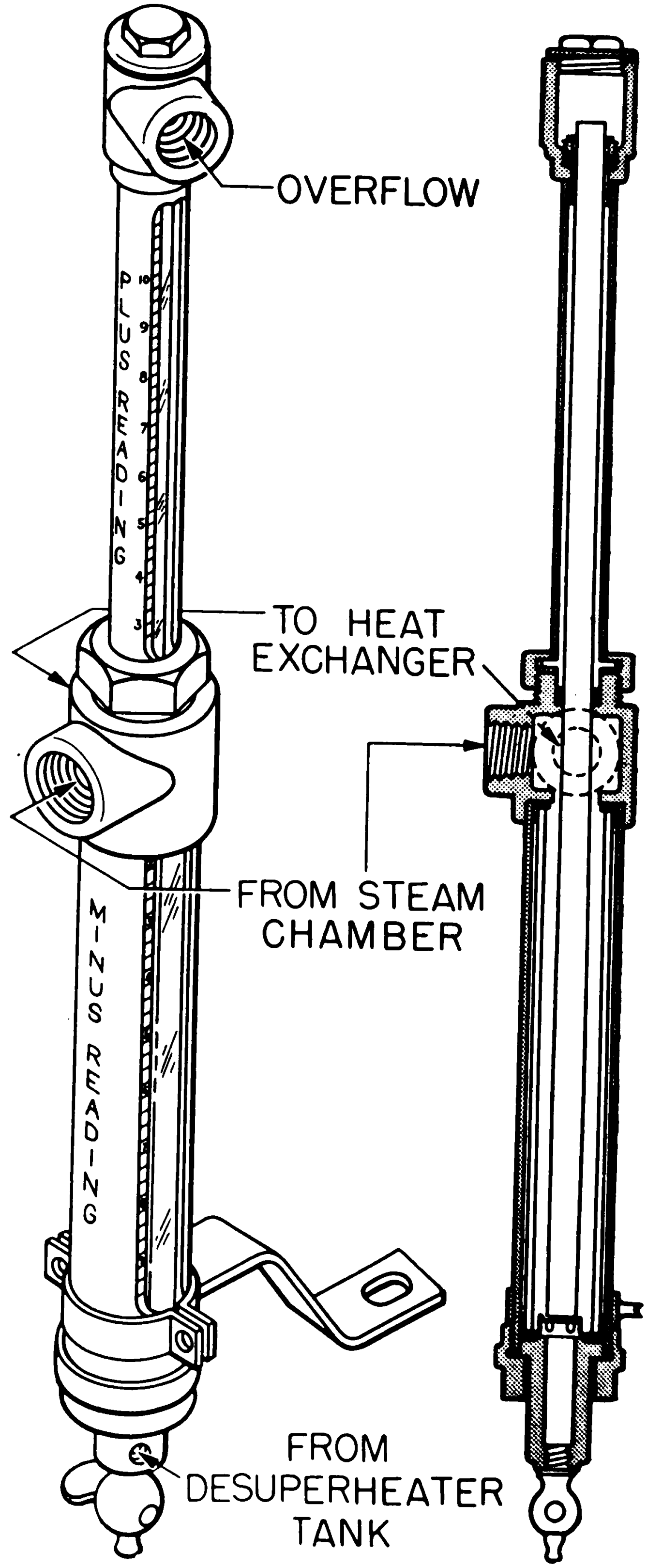


Figure 18-8.—Manometer.

boiling water in the distilling unit; and atmospheric pressure. The reading of the manometer is the difference between the water levels in the two tubes.

When the level in the inner tube is above the level in the outer tube, the pressure in the evaporator is above atmospheric pressure. When the level in the inner tube is below the level in the outer tube, the pressure in the evaporator is below atmospheric pressure. When the outer tube is completely full of water, the pressure in the evaporator is indicated solely by the level in the inner tube.

The manometer-level remains constant when the unit is operating with proper heat balance. When the distilling unit is operating properly, the reading level of the manometer will be behind the middle collar, or fitting, of the manometer. If the reading level becomes visible above or below this collar, the distilling unit should be adjusted. (See Factors Related to Distillation by Vapor Compression.)

COMPOUND GAGE AND PRESSURE SWITCH.—Some Model X–1 vapor compression units have been modified so that the electric heaters can be controlled automatically. In these modified units, the manometer is replaced by a compound pressure gage and a pressure-controlled switch. The gage indicates the vapor pressure within the evaporator.

The switch, connected to the gage piping, is opened and closed by means of a relay which is actuated by variations in the evaporator-shell pressure. The switch is set to turn heaters off or on so that the proper vapor pressure is automatically maintained.

BRINE-OVERFLOW PUMP.—A centrifugal, motor-driven, brine pump, with a capacity of about 4 gallons per minute, takes suction from the overflow connection of the evaporator unit; it discharges, through the heat exchanger, to overboard. One pump is required for each unit installed except on submarines, where the units are arranged to permit gravity flow, through the heat exchanger, to a brine-collecting tank.

OPERATION OF THE MODEL X–1 UNIT

Now that the principal parts of a vapor compression unit have been described, let's consider briefly what happens to the sea water which enters such a unit. Refer to figures 18–3 and 18–4 as you study the operational cycle of the unit. Pure water is distilled from sea water, when the unit is in operation, as described in the following paragraphs.

Cold sea-water feed enters the heat exchanger; it is there heated to about 190° or 200° F. From the heat exchanger, the feed goes into the evaporator. Here it passes through the downtake; into the bottom of the evaporator shell; and up through the tubes, where boiling and evaporation take place at atmospheric pressure. Of the incoming feed, from ½ to ⅔ evaporates; the rest flows out through the brine-overflow, thus maintaining a constant water level within the evaporator.

The steam rises and enters the vapor separator, where any particles of moisture present are separated from the vapor. The moisture is drained from the bottom of the separator and out of the evaporator through the vapor-separator drain. (In units which are equipped with a compound gage and a pressure-control switch instead of a manometer, the moisture separated from the vapor overflows with the brine.)

From the vapor chamber, the steam goes into the suction of the compressor; here distilled water is dropped onto the rotating impellers to desuperheat the steam as it is compressed. The steam is compressed until a pressure of 3 to 5 pounds above atmospheric pressure is attained. The compressed, saturated steam is discharged to the steam chest (into the space surrounding the tubes). As the saturated steam condenses on the outside of the ¾-inch tubes, the condensate drops down and collects on the bottom tube-plate. Every time a pound of compressed steam condenses, approximately a pound of steam is formed in the evaporator section; the compressor suction is thus kept supplied with the correct amount of steam.

The condensate is drawn off through a steam trap; it flows into the heat exchanger at a temperature of about 220° F. As it flows through the heat exchanger, the condensate gives up its heat to the incoming feed and is cooled to within about 18° F of the cold feed water temperature. Noncondensable gases are vented from the steam chest, through a small orifice. These gases, plus a small amount of steam, flow into the vent line; they carry the separated moisture into the heat exchanger. The steam condenses and gives up its heat to the feed.

The remaining feed which does not vaporize, flows continually into the funnel; out of the evaporator; and into the heat exchanger. The temperature of this brine which leaves the evaporator, through the overflow pipe, and then enters the external heat exchanger, is about 214° F. In passing through the heat exchanger, the hot brine raises the temperature of the sea-water feed.

Factors Related to Distillation by Vapor Compression

There are a number of factors related to the efficient operation of a vapor compression unit. A knowledge of these factors will make your job of operating and maintaining such units easier. Many questions may come to mind: Why does the vapor have to be compressed? What starts the heat cycle? To what extent are heaters used in maintaining the heat cycle? What about the loss of heat? How is heat balance maintained? These and other factors related to the operation of a vapor compression unit are considered briefly in the following paragraphs.

VAPOR COMPRESSION.—The need for compressing the vapor in a distilling unit involves several factors. The tubes of the steam chest serve two purposes: (1) to vaporize the feed and (2) to condense this vapor. The feed enters the heat exchanger at the temperature of sea water. The temperature of the feed is increased as the feed flows through the heat exchanger. The feed is already near its boiling temperature at atmospheric pressure when it enters the evaporator. As the feed passes through

the downtake, sufficient heat is absorbed from the compressed steam on the condenser side of the tubes to bring the temperature of the feed up to the boiling point.

As the compressed vapor from the compressor enters the steam chest, the vapor is condensed. For any given pressure, the boiling point of sea water is several degrees higher than the boiling point of fresh water. Therefore, the feed water passing up through the tubes of the steam chest is actually above 212° F. The vapor from this boiling feed does not have the characteristics of sea water; it is fresh water vapor, which, at atmosphere pressure, condenses at 212° F. When this vapor is compressed, however, its condensation point is higher than the temperature of the boiling feed-water in the tubes of the steam chest. When the compressed vapor enters the steam chest, the vapor comes in contact with external surfaces of the tubes. The temperature of these tubes, as we have noted, is lower than the condensation point of the compressed vapor; the vapor, therefore, condenses.

HEAT CYCLE.—The cycle is started by utilizing electric heaters to bring the feed water up to the boiling point, and to generate enough steam for compressor operation. When the compressor is adequately supplied with steam, the normal distillation cycle will begin; from this point, direct heat from the electric heaters is required only to make up heat losses. In operation, the heat input from the heaters is relatively small compared with the total heat input.

HEAT SUPPLY.—Heat is supplied to the unit in two ways: by means of the electric heaters; and by the work done by the compressor, in compressing the steam. The amount of heat supplied by the heaters is proportional to the number of heaters in operation; it can be varied, at will, by the operator. The energy supplied by the compressor, however, cannot be varied by the operator.

Heat transfer is affected by scale. If the amount and location of the scale in the evaporator tubes were to remain constant, the problem would be simple. But, as scale

accumulates the rate of heat transfer through the tube walls decreases. When the tubes are comparatively clean, an adequate amount of heat is transferred, the vapor is condensed, and space for additional vapor in the steam chest is made available at a constant rate. When scale formation retards the heat transfer, however, less condensation takes place unless the steam from the compressor has been compressed to a higher gage pressure.

FEED RATE.—The matter of feed rate in a distilling unit is very important; you must understand it thoroughly if you are going to operate the unit correctly. The amount of heat which the feed can pick up depends on the rate at which the feed flows through the tubes of the heat exchanger and through the steam chest of the evaporator. If the feed rate is low, the water picks up more heat during that passage because it is in contact with the hot tubes for a longer period of time. If the feed rate is high, the water picks up less heat, for it is in contact with the hot tubes for less time.

Experience has shown that, with the Model X–1 unit, a minimum feed rate of 70 gph is necessary if the rate of scale formation is to be kept low. The unit is designed, therefore, so that sufficient heat is supplied, when the compressor speed is about 2,000 rpm, to maintain vaporization of the feed at a minimum feed rate of 70 gph. If the total heat supply decreases enough to cause the feed to stop boiling, it is possible to bring the temperature back up to the boiling point by decreasing the feed rate. This practice, however, causes a material increase in the rate of scale formation; and a high degree of salinity in the evaporator. Lowering the feed rate below 70 gph is, therefore, not permissible, except perhaps in an emergency, and then only for a short period. If the heat input to the unit drops, the proper procedure is to increase the heat supply by turning on more electric heaters.

HEAT LOSS.—Heat is lost from the unit through the insulation, and in the hot-condensate and brine-overflow streams. The condensate is at a constant temperature for

any given discharge pressure. The rate of flow of the condensate depends on the compressor speed; it is substantially constant at any given compressor speed. Therefore, the rate of heat loss in the condensate stream is substantially constant at any given compressor speed. The brine overflow is also at a constant temperature; its rate of flow depends, however, on the feed rate. The rate of heat loss in the brine-overflow stream varies directly, then, with the feed rate.

HEAT BALANCE.—When more heat is supplied to the evaporator than is required to balance the heat losses, more steam is generated than the compressor can handle without change in speed. This will tend to build up a pressure above the feed in the evaporator section. This condition can be corrected by increasing the feed rate; this will result in more brine overflow, which, in turn, will increase the heat loss in the brine-overflow stream, and cause the pressure within the evaporator to decrease. (Changes of pressure within the evaporator are indicated on the manometer.) Turning off some of the electric heaters would produce the same effect; this would reduce the heat supply, of course, rather than increase the heat loss.

In this discussion, wherever reference is made to manometer pressure, it is to be remembered that some installations are fitted with a compound gage instead of a manometer. The pressure gage will register the same changes in the vapor pressure as the manometer.

Should the heat losses be greater than the heat supply, an insufficient amount of atmospheric-pressure steam will be generated. When this condition exists, the pressure in the evaporator above the boiling feed wili decrease slightly; a partial vacuum will be produced in the vapor separator; and the manometer will fall. To correct this condition; reduce the feed rate to decrease heat loss; or turn on more electric heaters to increase heat input.

The Model X–1 unit is kept in balanced, operating condition solely by adjusting the feed rate and by varying

the number of electric heaters in use. These adjustments are made until a satisfactory feed rate is obtained and a constant pressure is indicated by the manometer. (A steady manometer indicates a steady pressure in the evaporator.)

Operating Procedures

The following procedures apply to starting, operating, and securing the Model X–1 unit. With a few exceptions, which will be pointed out, the routine is the same whether the Type XB–1 compressor or the Model AAA–1 compressor is used. Information on difficulties related to starting and operating the unit is not included with the following procedures; such information is provided in a more advanced training course for Enginemen and in *Bureau of Ships Manual,* Chapter 58.

STARTING ROUTINE.—The following procedure should be followed when a Model X–1 distilling unit is being placed in operation.

1. Turn on the main electrical switch.
2. Line up the valves in the feed, condensate, brine-overflow, and vent lines to provide normal operating flow in the various circuits.
3. Start the feed pump. Check the feed-pressure gage; vent the feed pump, if necessary.
4. Open the flow-control valve and observe the flow in the feed rotameter. Adjust the feed rate by means of the flow-control valve, to about 90 gallons per hour.
5. Line up the valves in the brine-overflow line, and start the brine pump (if installed). Check the brine pump discharge pressure; vent the pump, if necessary.
6. When the flow begins in the brine rotameter, the evaporator is filled with water. At this time, stop the feed pump; and secure the flow-control valve.
7. When the flow stops in the brine-overflow rotameter, secure the brine-overflow pump.
8. Turn on all the electric heaters; check the ammeter as each switch is thrown, to be sure that all heaters are operative. (These electric heaters will burn out unless

they are submerged in water when they are operating. Do not turn on the heaters without first filling the unit with water to the correct level, which will be indicated by flow in the brine-overflow rotameter.)

Check the following items in preparation for starting the compressor motor:

9. The compressor bypass valve must be wide open when the compressor is started.

10. Belts must have some slack. (Belts that are too tight will cause the bearings of the compressor and the motor to bind; they will also overload the motor.)

11. Check both oil levels in the compressor; be sure that levels are at the marks on the gage glasses. Add oil as necessary. Use only Navy #1150 or SAE 70 oil for Type XB compressors; and Navy #9370 or SAE 40 oil for AAA–1 compressors. (Oil levels should not be checked when the compressor is running. However, the unit should be secured every 24 hours and the oil level checked. Oil should be added as needed but not when the compressor is running. The oil should be changed when the evaporator is cleaned.)

12. Check the position of the rheostat on direct current motors. Direct current motors must always be started at the lowest speed; that is, with the rheostat turned all the way to the left.

13. Check the water level in the desuperheater tank to be sure that it is at least half-full. If refilling is required, distilled water must be used.

14. After the preceding checks have been made, and about 2 hours after turning on the heaters, start the compressor motor. (Check the motor current. If it is more than 1.2 times the full-load ampere-rating shown on the nameplate, stop the motor; wait 10 minutes, and then restart the motor.)

15. Start the desuperheater drip at a very rapid rate (not less than 200 drops per minute).

16. Check the compressor speed. For Type XB–1 compressors, the normal speed is 1,300 rpm; for Model AAA–1 compressors, 2,000 rpm.

The feed pressure and the motor speed should remain substantially constant if the best operation is to be obtained. If the line voltage varies, the speed of the compressor and the amount of condensate will also vary. With direct current motors, the field rheostat can be used to control the compressor speed and, therefore, the amount of condensate.

17. By means of the filling valve, fill the manometer up to the center. The manometer should be filled shortly after the compressor is started. (If the unit is still taking in air through the manometer the water will be drawn up. However, as soon as enough vapor is generated to supply the compressor, the unit will stop taking air; and the water will drain back from the vapor separator to the manometer.)

18. When the water seal is established at the bottom of the manometer, add enough water, through the filling valve, to fill the outer tube. The water level in the outer tube will then be at the zero mark. As the rate of boiling increases, the pressure in the vapor separator will go up; this increased pressure will depress the water level in the outer tube and raise the level in the inner tube. A reading obtained under these conditions is considered a "plus" reading, since it indicates a pressure greater than atmospheric in the unit. The reading which is taken is the vertical distance, in inches, between the two water levels; this reading is "plus" if the level in the inner tube is above that in the outer tube, "minus" if it is below.

19. When the manometer reads +2 inches, start the feed pump; and open the flow-control valve to the point where a flow of 5 gallons per hour is indicated in the feed rotameter.

20. Start the brine-overflow pump (when installed); vent the pump, if necessary.

21. When the manometer reads +4 inches, increase the feed rate to 10 gallons per hour.

22. When the manometer reads +6 inches, increase the feed rate to 15 gallons per hour.

23. Vent the condensate trap and the condensate pump (if installed) for several seconds; then, start the condensate pump. If the pump does not operate properly, check the glands; they may require tightening in order to prevent air leakage into the pump.

24. When the manometer level starts to go above a +6-inch reading at the 15-gallon feed rate, start closing the bypass valve slowly; as this is done, maintain a manometer reading above +3 inches. Be careful that the compressor-discharge pressure does not go above 6 pounds for AAA–1 compressors, nor above 7 pounds for XB compressors. (Abnormal compressor-discharge pressure is the first indication of trouble. Compressor-discharge pressure varies with the speed of the compressor and with the scale conditions inside the tubes where the sea water is vaporized. When compressor speed is constant, then, compressor-discharge pressure is an indication of the amount of scale in the evaporator.)

25. When the bypass valve is completely closed, increase the feed rate, in increments of 15 to 20 gallons per hour; these increases should be made, at intervals which do not exceed 30 seconds, until the feed rate is 70 gallons per hour. Do not increase the feed rate, however, when the manometer is falling.

OPERATING ROUTINE.—After the unit has been started, adjustments will be required for some time, until the unit is balanced and the manometer is showing a constant reading between +2 inches and —4 inches.

1. To balance the unit, first set the feed rate at its minimum value. Then, cut out heaters until the manometer starts to drop; this indicates that the heat losses are exceeding the heat input. Cut in one heater switch; and gradually increase the feed rate until the manometer remains constant somewhere in the range between +2

inches and -4 inches. When a ship is in heavy seas, or when the voltage to the heaters and compressor motor is fluctuating, it is desirable to balance the unit at a somewhat higher pressure; and to operate with a manometer reading between $+2$ inches and $+4$ inches.

2. Adjust the desuperheater drip to give a minimum compressor-discharge pressure. Increasing the number of drops per minute lowers the discharge pressure to a certain point; beyond this point, increasing the desuperheater drip will raise the compressor-discharge pressure. The desuperheater drip should be kept adjusted to hold the low point of the compressor-discharge pressure. As the evaporator scales up, more drip will be required; a dirty unit, just before cleaning becomes necessary, may require a small steady stream through the sight glass.

3. Other operating adjustments:
    a. To increase the brine overflow, increase the feed.
    b. To decrease the brine overflow, decrease the feed.
    c. To make the manometer rise, either turn on additional heaters or reduce the feed rate.
    d. To make the manometer fall, either increase the feed rate or turn off electric heaters.
    e. To increase the condensate rate, increase the compressor speed
    f. To decrease the condensate rate, decrease the compressor speed

SECURING ROUTINE.—The procedure for securing the unit is as follows:

1. Fill the desuperheater tank.
2. Turn off the electric heaters.
3. Open the bypass valve.
4. Stop the compressor motor.
5. Secure the condensate pump.
6. Secure the desuperheater drip.
7. Open the flow-control valve wide; continue feeding for at least 15 minutes in order to flush the unit. An even longer flushing period is desirable from the point of view of retarding scale formation. (In submarine installations,

where longer flushing periods are required, adjust the feed rate until it is the same as the overflow rate.)

8. Secure the flow-control valve and the feed pump.

9. When the flow stops in the brine-overflow rotameter, secure the brine-overflow rotameter and the brine-overflow pump. The unit must always be left full of sea water between operating periods.

10. Secure sea-chest valves.

11. Pull main electrical switch.

WATCH READINGS AND THE LOG.—It is important that an accurate, up-to-date log be maintained on each distilling unit. The log should contain a record of readings taken hourly during the period of plant operation; and a statement of maintenance work performed.

It is recommended that the hourly readings include: time of reading; hours run since last cleaning; compressor pressure; compressor rpm; feed rate (gph); overflow rate (gph); gallons of condensate distilled; feed pressure; manometer reading; number of heaters in use; volts; amperes; and condensate salinity.

The following notations should be made under "remarks": time distillation started; time unit secured; time desuperheater tank filled; date evaporator cleaned; and date heat exchanger cleaned.

QUIZ

1. On the basis of the source of heat used to produce vaporization of sea water, name two types of distilling plants.
2. What are the three main components of the Model X type plant?
3. What are the two principal elements of the evaporator in a Model X unit?
4. How are the noncondensable gases removed from the steam chest of a Model X unit?
5. In vapor compression units, what is used to bring the temperature of the feed up to the boiling point?
6. In a Model X unit, what useful purpose is served by the brine which remains after evaporation of the feed?
7. Approximately what portion of the sea-water feed supplied to a Model X–1 unit is evaporated?
8. What removes liquid from the vapor before it enters the vapor compressor of a Model X unit?
9. What is the principal purpose of the variable-pitch sheave in the compressor-drive of a Model X unit?
10. How are the bearings at the drive end of a AAA-1 compressor lubricated?
11. What is the function of the heat exchanger in a Model X unit?
12. Name the four flow-paths within the heat exchanger of a Model X unit.
13. In surface-craft installations, pumps are included in which of the circuits of a Model X distilling unit?
14. What is the function of the bypass valve on the compressor of a Model X unit?
15. In a Model X unit, what keeps steam from flowing with the condensate from the condensing section of the steam chest to the heat exchanger?
16. What is the purpose of a rotameter?
17. What may be used to indicate the pressure of the steam in the vapor separator of a Model X unit?
18. In a Model X unit, how does the process of condensation aid in keeping the suction side of the compressor supplied with the correct amount of steam?

CHAPTER 19

LOW-PRESSURE STEAM DISTILLING PLANTS

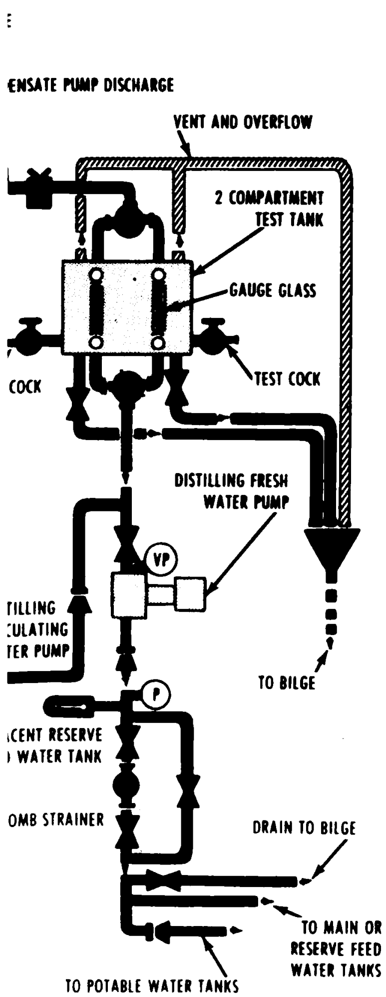
Steam distilling plants are operated, directly or indirectly, from power-plant boilers or from auxiliary boilers. Steam distilling plants are divided into two groups, low pressure (LP) plants and high pressure (HP) plants; these groups differ mainly in the pressures in the heating elements and in the evaporator shell. In both groups, the basic units are the same; an evaporator, or boiler; and a condenser, or distiller. High-pressure steam distilling plants are installed on comparatively few naval ships.

LOW-PRESSURE STEAM DISTILLING PLANTS IN GENERAL

Low-pressure steam distilling plants, instead of vapor compression plants, are ordinarily installed on all steam-driven vessels, because an ample supply of auxiliary-exhaust steam is available and because the desired capacity of the distilling plant is greater than that of vapor-compression units. Low-pressure plants are also installed on some Diesel-driven vessels; in these cases, steam must be supplied by an auxiliary boiler.

Types of LP Plants

Steam distilling plants may be classified according to the number of stages of evaporation which take place during the operational cycle; and by the number of shells, or cylinders, in which the stages of evaporation take place.



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When there is only one stage of evaporation, the plant is called SINGLE-EFFECT plant. When evaporation goes through two or three stages, the plants are called DOUBLE-EFFECT or TRIPLE-EFFECT plants, respectively. Low-pressure steam plants in use in Naval ships are of either the double- or triple-effect type.

In a double-effect plant, the stages of evaporation take place in two evaporator chambers. These chambers may be within a single evaporator shell, or within two separate evaporator shells. A double-effect plant in which evaporation takes place within a single evaporator shell is commonly called a DOUBLE-EFFECT SOLOSHELL LP plant. A plant which includes two separate evaporators is called a two-cylinder (shell), double-effect plant. The three stages of evaporation in a triple-effect plant take place in three separate evaporators. Schematic drawings which show the arrangement of a Soloshell double-effect plant, a two-shell double-effect plant, and a three-shell triple-effect plant are provided in figures 19–1, 19–2, and 19–3, respectively.

Capacities of LP Plants

Low-pressure steam distilling plants are built with nominal capacities of 4,000; 8,000; 10,000; 12,000; 20,000; 30,000; and 40,000 gallons per day (gpd). The ratings of the plants are based on an initial steam pressure of 5 psig to the tube nest of the first-effect evaporator. The four smaller capacity distilling plants are double-effect soloshell units. The 20,000 gpd plants are usually designed for double-effect operation; however, some 20,000 gpd plants are three-shell triple-effect plants.

It is beyond the scope of this training course to provide detailed information on all types of low-pressure distilling plants. For this reason only a general discussion of the various types of low-pressure distilling plants is provided; from it you can get an idea of how steam distilling plants operate. The operation of the Soloshell double-effect plant is emphasized.

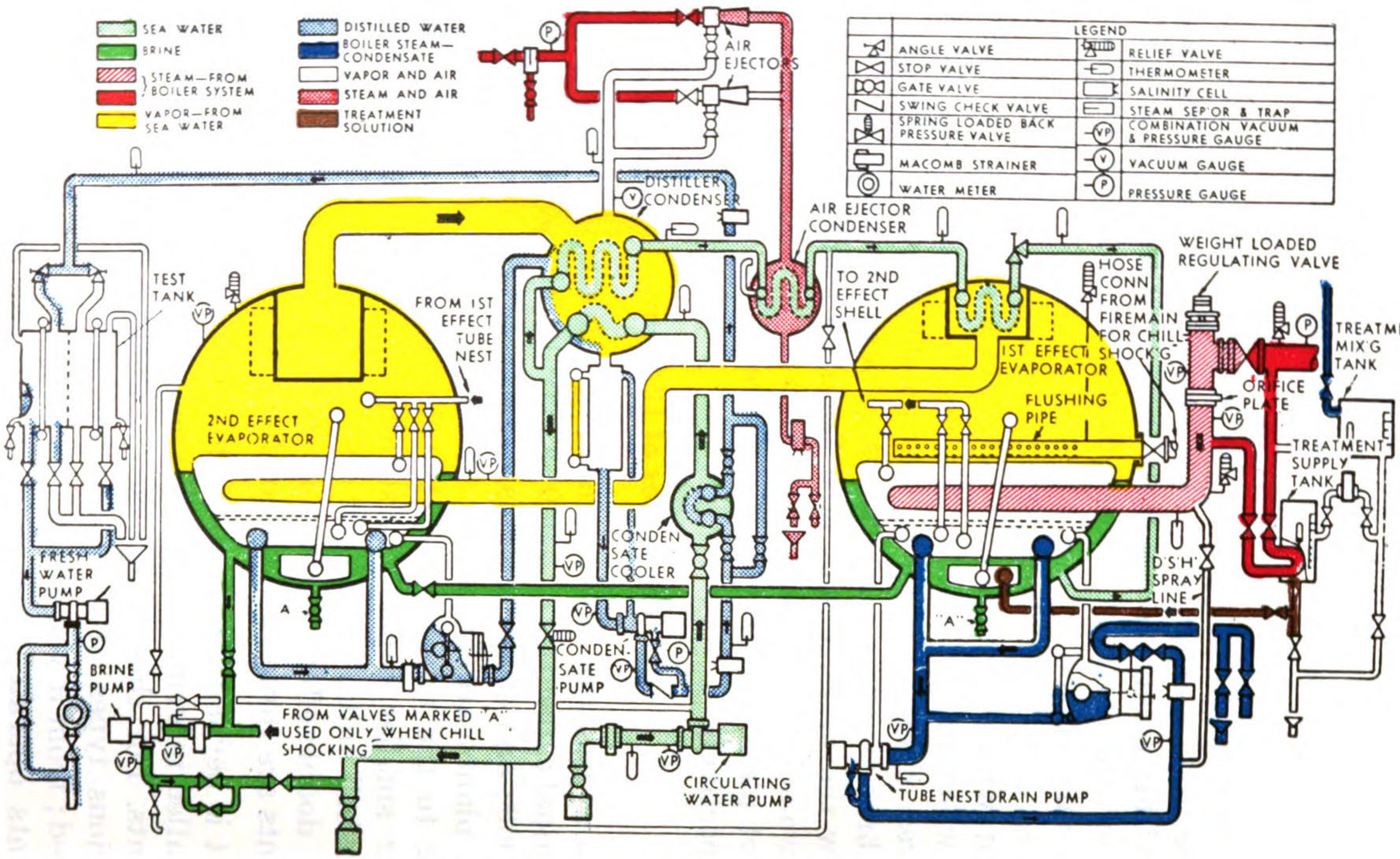

Figure 19–2.—Two-shell double-effect LP distilling plant.

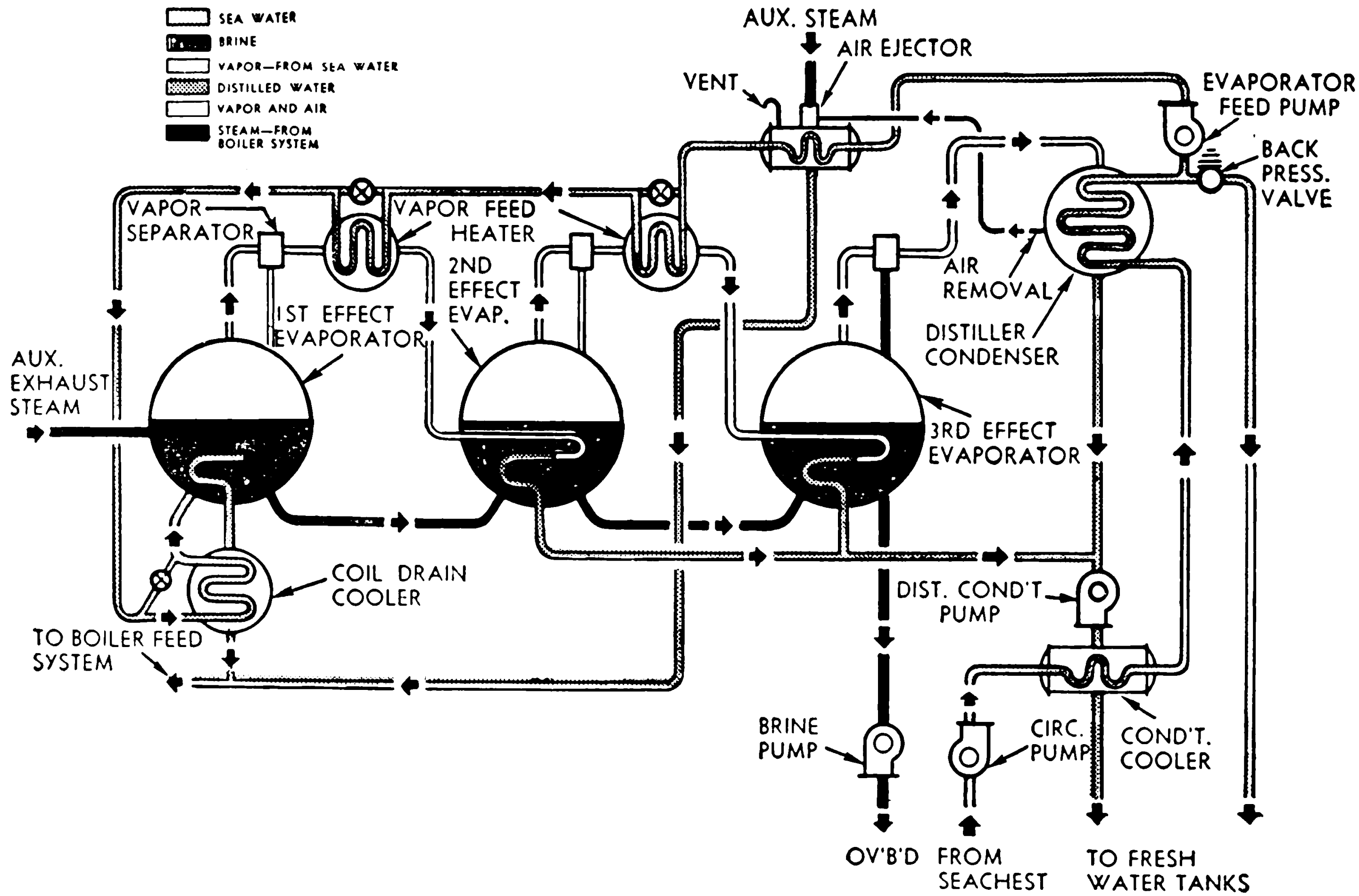

Figure 19—3.—Three-shell triple-effect LP distilling plant.

SOLOSHELL DOUBLE-EFFECT PLANTS

Virtually all low-pressure distilling plants up to and including the 12,000 gpd plant are of the Soloshell double-effect type. In this type of plant, the evaporator and the condenser are within a single cylinder. The arrangement of the parts included in the shell is shown in figure 19–4.

The single cylindrical shell is mounted with its longitudinal axis in a horizontal plane. A vertical partition plate, parallel to the longitudinal axis, divides the shell into two evaporator chambers. Each of these chambers has a separate, removable tube-bundle (the first- and second-effect coils in fig. 19–4), bolted to the front head of the shell. The vapor-feed heater is built into the upper part of the first-effect shell; the heater has a removable tube-bundle bolted to the front head of the shell.

The distilling condenser (condensing and feed-heating sections) is built into the upper part of the second-effect shell. The condenser does not have a removable tube-

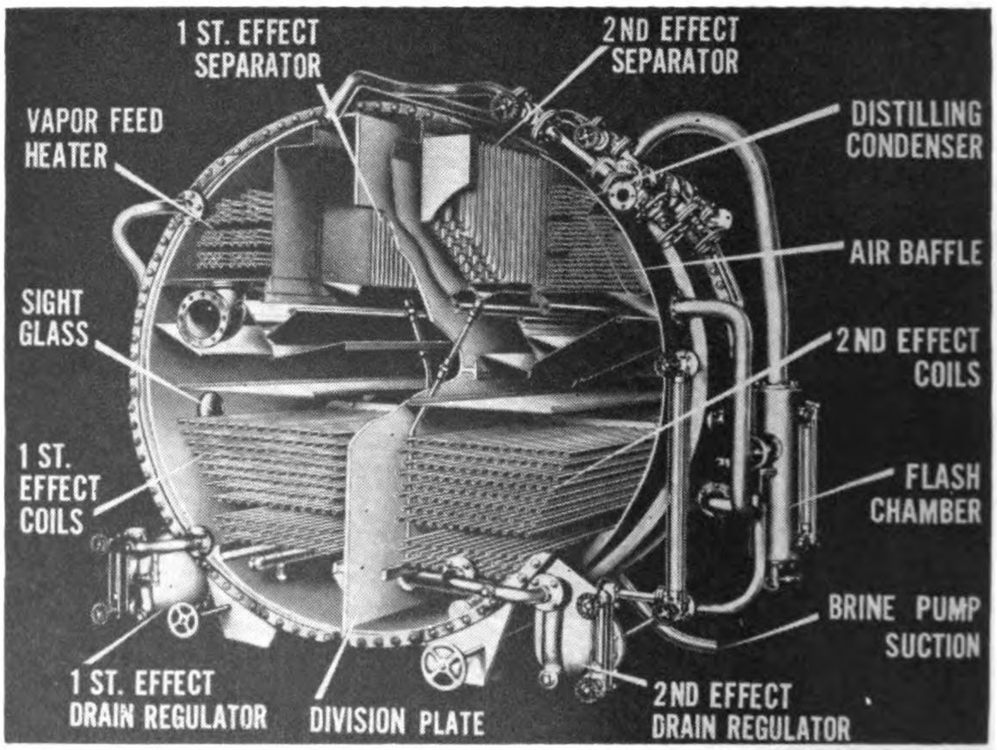

Figure 19–4.—Arrangement of components within the cylinder of a Soloshell distilling plant.

bundle; the tube sheets project beyond the front and rear heads of the shell, however, so as to provide access for the cleaning and replacement of tubes.

The only part of the heat exchanger equipment not in the distilling condenser is the air-ejector condenser. The air-ejector condenser is in a separate shell; it is located so that the necessary piping connections can be made conveniently. (See fig. 19–1.)

For the purpose of explaining the operation of a Soloshell low-pressure distilling plant the piping system of the plant may be divided into seven different circulating systems, or circuits. (With few exceptions, the information given here is also applicable to two-shell double-effect plants and to triple-effect plants.) The seven circuits, together with the necessary vent connections and drain connections to the units of the plant, make up the complete piping system. The operation of the plant and the functions of the units of the plant will be easier to understand if you trace the circuits on the schematic drawing, figure 19–1, as you study the following descriptions of the circuits.

Circulating Water Circuit

The circulating-water pump of the condenser takes a suction from the sea and discharges through the condensate cooler and the distilling condenser. A strainer is provided in the suction piping to the pump. The cooling water usually makes one pass through the tubes of the condensate cooler and two passes through the tubes of the distiller condenser. The cooling water is then discharged overboard, usually through a spring-loaded valve which is designed to maintain a 5 psig back-pressure on the tubes and heads of the distiller condenser.

Evaporator-Feed Circuit

Part of the sea water from the circulating-water circuit is used to feed to the first-effect evaporator. The back-pressure valve in the circulating-water discharge line maintains sufficient head to deliver feed to the first-effect evaporator chamber. (Triple-effect plants use an

evaporator-feed pump.) In the circuit to the first-effect chamber, the feed passes, in sequence, through the feed-heating section of the condenser, through the air-ejector condenser, and through the vapor-feed heater.

The components in the feed line to the first-effect evaporator chamber are arranged so that the feed water passes from one heater to the next in the order of the temperature levels in the various units. The heating medium for the feed-heating section of the condenser is the vapor produced in the second-effect evaporator, which is at a lower temperature than the heating medium for the first-effect vapor-feed heater.

The feed water enters the first-effect evaporator chamber well below the water level in the chamber. Most evaporators are provided with perforated, internal pipes, which distribute the feed water evenly as it enters the chamber.

Generating-Steam Circuit

The generative steam for the plant is obtained, through a weight-loaded regulating valve, from the supply line. The valve is set to maintain a constant steam pressure (1 to 5 psi, depending on the cleanliness of the tubes) to the tube nest of the first-effect evaporator.

An orifice plate is installed in the steam line between the regulating valve and the entrance to the tube nest. The orifice in this plate is designed to limit the amount of steam entering the first-effect tube nest to the amount which is required for the production of the plant's designed output of distilled water.

The steam becomes superheated as it passes through the regulating valve and the orifice. In order to avoid excessive tube-nest temperatures, which lead to the rapid formation of scale, most plants are provided with a desuperheating connection. By means of this connection, hot water, which is piped from the first-effect tube nest drain pump, is sprayed into the steam line near the steam head of the first-effect tube nest. The operator of the distilling plant adjusts the amount of desuperheating

spray so as to keep the temperature of the steam at the correct level.

The generating steam is condensed in the tube nest of the first-effect evaporator; it gives up its latent heat of vaporization to the feed water which surrounds the tubes in the first-effect evaporator shell. The condensate from the first-effect tube nest may be discharged to the main condenser or to the dynamo condenser; to the fresh-water drain-collecting system; or to the deaerating feed-tank. This condensate is somewhat contaminated with oil, grease, and boiler compound; it is, therefore, not potable water.

In order to prevent the generating steam from blowing through the tubes before it has given up its latent heat, a drain regulator is provided in the condensate line. This drain regulator consists of a body and a cover, which enclose a rotary valve which is operated by a ball float.

Frequently a tube-nest drain pump is installed for the purpose of discharging drains into the boiler-feed system or into the deaerating feed-tank. Atmospheric, or trapped, drains would prevent the operation of the first-effect tube nest at pressures below atmospheric, and would fail to provide sufficient head to force the drains into the feed tank. In some plants, drain connections are made to a main condenser or to an auxiliary condenser; plant operation is then possible even if the tube-nest drain pump should fail. The tube-nest drain is usually provided with a valve discharge; in the event of a leaking tube-bundle, the drains can be discharged to the bilge and contaminating the boiler-feed system can thereby be avoided.

Vapor Circuit

Steam generated in the evaporator shells by the evaporation of the feed water is referred to as vapor, to prevent confusing it with the generating steam supplied to the first-effect evaporator tubes from the outside source.

During the evaporating process the vapor separates from the brine, at the water surface; although the vapor

itself is pure, small particles of raw, unevaporated, feed water are entrained by, and carried up with, the vapor. Unless the particles of feed water are removed they will be carried over with the vapor and will contaminate the distillate. To prevent such contamination, these particles of feed water are removed from the vapor by a series of baffles located above the water surface in the evaporator chambers, and by additional baffles, or vanes, in the vapor separators. The vapor is forced to change its direction several times, as it passes around the edges of the baffles, or vanes, at high velocity. The particles of entrained moisture are entrapped and removed by the hooked edges of the baffles; they are then led to drain lines.

After passing through the vapor separators on its way to the second-effect tube nest, the vapor generated in the first effect passes through the first-effect vapor-feed heater; here part of the vapor is condensed, giving up its latent heat of vaporization to the feed water which passes through the tubes of the heater.

The remaining vapor and condensate pass into the tube nest of the second-effect evaporator. The absolute pressure in the second-effect evaporator shell is maintained at a lower level than that in the second-effect tube nest; because of the resulting temperature difference the latent heat of the vapor in the tubes is transferred to the second-effect water (brine). Thus, the vapor which was generated in the first-effect shell is used to boil and vaporize the brine in the second-effect evaporator shell. The vapor generated in the second-effect evaporator passes through the second-effect vapor separators to the distilling condenser.

Brine Circuit

Since only part of the feed water is evaporated in the first-effect evaporator chamber, the density and salinity of the remaining water are increased. Although it serves as feed to the second effect, this water is ordinarily referred to as "brine," to distinguish it from sea water. Thus, the brine circuit includes the feed connection be-

tween the first- and second-effect chambers. The pressure differential between the first and second effects, even though it is comparatively low, is sufficient to transfer the brine from the first effect, through a manually controlled feed-regulating valve, to the second effect.

The brine is distributed in the second-effect chamber by means of perforated, internal, feed-distributing pipes, which are similar to those in the first-effect evaporator. The arrangement of these pipes is such as to prevent the vapor which is flashed from the brine (due to the pressure drop from the first-effect shell to the second-effect shell) from causing violent agitation in a localized area of the second-effect evaporator chamber; the tendency toward priming is thus prevented.

The brine-overboard pump takes suction from the second-effect shell, through a Macomb-type strainer, and discharges into the overboard-discharge line of the distiller circulating pump. To permit rapid dumping of the first and second-effect chambers, there are also provided suction connections from the brine-overboard pump direct to these chambers. These connections, which are not used in normal operation, are usually fitted with locked valves. The brine-overboard pump operates under a vacuum on the suction side; the gland must, therefore, be sealed by water from the discharge of the circulating pump. To prevent the pump from becoming vapor-bound, it is usually vented to the second-effect shell.

A uniform rate of feed to the first and second effects is obtained, in most plants, by the use of manually-controlled feed valves to each effect; and by adjustment of the bypass valve at the brine-pump discharge. On some vessels, automatic control of the water level in each evaporator chamber is accomplished by a weir-type level controller. An adjustable-height weir is provided at the brine outlet from each shell. The feed from one effect to the next is, then, only the amount of brine that spills over the weir; this is the excess of feed over evaporation in the effect containing the weir in question.

Fresh-Water Circuit

The condensate which is formed by the condensation of the first-effect vapor in the second-effect tube nest is combined with the condensate from the condenser. The total of the condensed vapors makes up the fresh-water output, which is routed through the fresh-water circuit.

The condensate from the second-effect tube nest passes through a drain regulator, which maintains a water seal, to the second-effect flash chamber. As the condensate passes through the drain regulator, the pressure on the second-effect tube-nest drains is reduced to that in the flash chamber. Due to this reduction in pressure, part of the hot water flashes into vapor. This vapor is separated from the water in the second-effect flash chamber; it is then led into the distiller condenser, where the vapor is finally condensed. A centrifugal, condensate pump takes suction from the flash chamber and discharges the fresh water through the condensate cooler, generally to the measuring-and-test tank.

Some plants have an electrical safety device which functions to prevent contamination of the fresh water. The device, a salinity cell located in the fresh-water line, closes the fresh-water lines to all the ship's tanks and discharges the output of the entire plant to the bilges or to the sump tanks when predetermined salinity limits are exceeded. When this device is installed, the measuring-and-test tank and the fresh-water pump are omitted; the condensate pump is utilized for fresh-water distribution to the ship's tanks.

Air-Removal Circuit

Air enters the plant mainly with the evaporator feedwater, in which the air is dissolved. As this feed water is heated, the dissolved air is rejected and tends to collect in various units of the plant. Air also enters the plant with the generating steam; through various, small leaks at pump glands; and through imperfect vacuum joints. Since the distilling condenser is at the lower end of the heat-flow cycle of the distilling plant, the absolute pres-

sure within this unit is lower than that in any other unit of the plant; the air, therefore, collects in the condenser. Continuous removal of the air must take place in order to maintain the vacuum and to prevent the air from disrupting the vapor flow to the cooling surfaces. The air is removed from the plant by air ejectors.

Two single-stage air ejectors are usually provided for removing the noncondensable gases and air which accumulate in the distilling condenser. One of these ejectors is capable of removing air from the distilling plant under normal conditions of air leakage; the other ejector is available as a standby or for use under abnormal conditions of air leakage.

The air-ejector suction piping is connected to the air-precooling section of the distilling condenser. The main function of the air-precooler is to cool the air flowing to the air ejector suction line. Cooling causes any vapor in the air to condense. The condensed vapor then drains to the bottom of the distiller shell. If the air were not cooled and the vapor not removed, the volume of air and vapor flowing to the air ejector would be greater than could be handled satisfactorily.

The steam for the distiller air-ejectors is supplied from the auxiliary steam line. Since the capacity of the ejectors is comparatively small, the pressure used is usually not over 135 psig; this relatively low pressure makes use of a small orifice nozzle, which would be apt to clog, unnecessarily. Steam strainers are provided in the steam-supply line, ahead of the reducing valve and ahead of each ejector nozzle. A pressure gage and a relief valve are usually installed in the supply piping, between the reducing valve and the jets of the ejectors.

The jet of motive steam issuing from the nozzle of the air ejector entrains the air and noncondensable vapors drawn from the distilling condenser and compresses the mixture until its pressure is slightly above atmospheric. The steam is condensed and the air is cooled in the air-ejector condenser, where the vapor gives up its latent

heat to the evaporator feed-water passing through the tubes of the condenser. The air and noncondensable gases are vented to the atmosphere, either directly into the compartment or through a vent to the weather deck. The condensate is returned to the boiler-feed system, usually through the fresh-water drain-collecting system.

TWO-SHELL DOUBLE-EFFECT LP PLANTS

Soloshell and two-shell, double-effect, distilling plants are basically the same, except that the latter type is designed so that the evaporator chambers are in two separate shells (fig. 19–2). The most commonly used 20,000 gpd, double-effect plant is of the two-shell type. Two horizontal cylindrical shells, one for each effect, are usually mounted with their axes parallel. In two-shell plants, you will also find that the distilling condenser and the condensate cooler are in separate shells, and that they are usually mounted between the two evaporator shells.

TRIPLE-EFFECT LP PLANTS

The triple-effect distilling plant is similar to the double-effect plant, except that the triple-effect plant has an intermediate evaporating stage. A standard 20,000 gpd, triple-effect plant consists of three horizontal, cylindrical shells set side by side, with their axes parallel. (See upper portion of fig. 19–5.)

The tube bundles can be withdrawn through the front head of each shell. The first- and second-effect vapor-feed heaters are built into the front end of the second- and third-effect evaporator shells. The distilling condenser is within the third-effect shell. The air-ejector condenser and the condensate cooler, in separate shells, are mounted on the third-effect shell. The arrangement of the components within the first-effect evaporator shell of a triple-effect plant is shown in figure 19–5.

Some 20,000 gpd, triple-effect plants are designed with three horizontal shells which are bolted together end to end. The vertical-partition plates between the sections (shells) form the three effects. The tube bundles can be

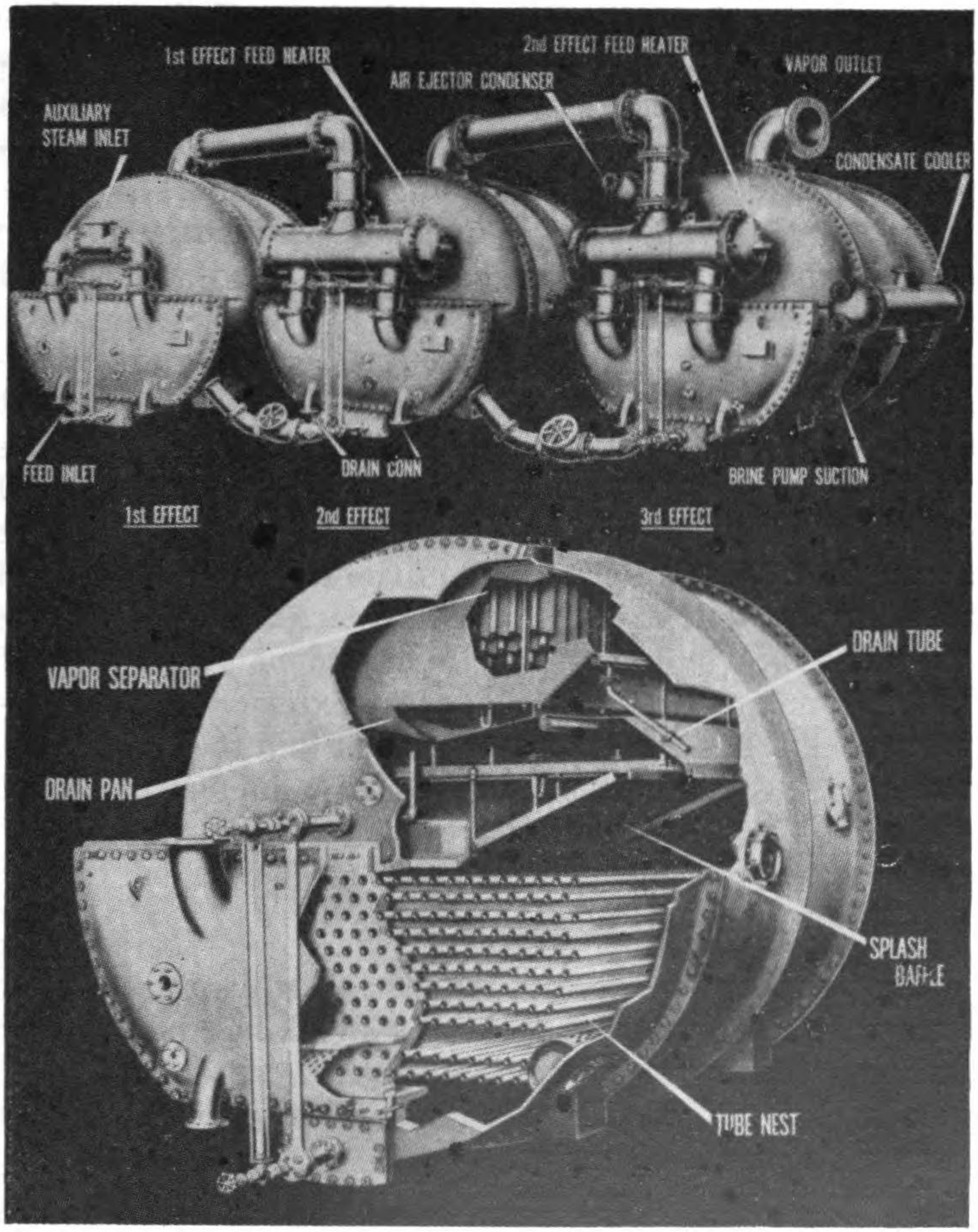

Figure 19–5.—Arrangement of components in the first-effect evaporator shell of a triple-effect plant.

withdrawn, horizontally, through one side of the cylinder. Vapor separators, in independent shells, are installed in the vapor piping between effects (cylinders) ; and between the third effect and the distiller condenser. The first- and second-effect vapor feed heaters are in separate shells; and are mounted in the piping at the inlets to the second and third-effect tube bundles, respectively. The

two sections of the distilling condenser and the condensate cooler are built into a single shell; they are independently mounted, as space and piping arrangements permit. The air-ejector condenser is also a separately-mounted unit.

The standard 30,000 gpd, triple-effect plant is similar to the standard 20,000 gpd plant, except for the increased size of the units.

Triple-effect plants with 40,000 gpd capacity are basically the same as plants with lesser capacities, except that the units and parts are larger. Some 40,000 gpd, triple-effect plants are arranged exactly like the standard 20,000 gpd plant (fig. 19–2). In other 40,000 gpd plants, the arrangement is similar to that of the standard 20,000 gpd plant, except that the vapor feed heaters and the distilling condenser are built as three independent units, each of which is mounted separately on the exterior of the separator shells. The air-ejector condenser and the condensate cooler are also in independent shells. A number of 40,000 gpd plants are designed and arranged like those 20,000 gpd plants in which the three shells are bolted end to end.

CHLORIDE TESTS

The primary purposes of the distilling plant are to produce palatable and pure water for drinking and cooking, and to produce water with low mineral content, for such uses as boiler feed. The distillate must, therefore, meet certain standards of purity.

It was formerly considered that water having a chloride content up to 1.25 equivalents per million (epm) (5.0 grains of sea salt per gallon) was fit for drinking, cooking, or bathing, provided that the absence of bacteria could be assured. It has been established by comprehensive tests that if the chloride content of the water from a low-pressure distilling plant is held at or below 0.065 epm when the plant is operating on sea-water feed, no dangerous bacteria will be found, even when the feed water is highly contaminated. Steam or true water vapor cannot carry these minute organisms; if all entrained

moisture can be removed from the vapor, therefore, the vapor and its condensate will be bacteria-free. Under such conditions of operation, no additional treatment with chemicals or with heat is necessary.

Any chloride content above 0.065 epm indicates contamination by leak or by carry-over; such water may be highly-dangerous in its disease-carrying properties if the original feed-water is contaminated with bacteria. Therefore, water from a distilling plant must not be discharged to a ship's drinking-water tanks when its chloride content exceeds 0.065 epm. Since the suitability of water for various shipboard uses is based upon the chloride content of the water, means for checking chloride content are necessary. Chloride content is determined by indicating devices and by chemical tests.

Testing Distillate With Electrical Salinity Indicators

A constant check is maintained on the chloride content of the distillate by means of electrical salinity indicators which are installed throughout low-pressure distilling plants. An electrical salinity indicator consists of a number of electric salinity cells which are located at various points in the plant, such as in the fresh-water pump discharge, in the distiller-condensate pump discharge, in the tube-nest drain, and in the air-ejector condenser drain. These cells are connected to a salinity-indicator panel located on a bulkhead near the plant.

Since the electrical resistance of a solution varies with the amount of ionized salts in solution, it is possible to determine the salinity of a solution by measuring the electrical resistance of the solution. The salinity-indicator panel is equipped with an ammeter which is calibrated to give direct readings of either epm or gpg (grains per gallon). Since the resistance of the solution also varies with temperature, however, a temperature-compensator must be set at a value corresponding to the temperature of the solution.

When reading the dial of an electrical salinity indicator, be sure that you know what you're reading. Some

salinity indicators are still calibrated in grains of sea salt per gallon. Since this unit is no longer used for reporting water analyses, any reading taken in gpg must be converted to epm. To effect this conversion, multiply the gpg (meter reading) by 0.261 to get the chloride epm. For example, a meter reading of 0.23 grains of sea salt per gallon is equal to 0.23×0.261, or 0.06, epm chloride.

To check an electrical salinity indicator, proceed as follows:

1. Turn on the power to the indicator.

2. Set the temperature-compensator at 110° F.

3. Depress the test button; hold it down until the reading is taken.

4. Read the indicator. The reading should be approximately 1 grain. If the salinity indicator does not give a reading of approximately 1 grain, the instrument is not correctly calibrated; it should then be checked by an I. C. Electrician.

Chemical Chloride-Testing of Distillate

All vessels are provided with the equipment required for making salinity tests by means of chemicals. Chemical tests are made to check and supplement the electrical indicator-system of low-pressure plants.

The chemical chloride test is applied to samples of water drawn out through the test cocks of the measuring and testing tanks. Specific instructions for making the tests are generally posted on or near the water-testing equipment cabinet which is provided in each evaporator space. The instructions may also be found in chapter 56 of *Bureau of Ships Manual.* The general procedure is as follows:

1. Fill the 100-ml, graduated cylinder with a distillate sample from the test tank; pour it into a clean, dry casserole.

2. Add 5 drops of chloride indicator to the sample. The water should turn violet or red, depending upon its alkalinity.

3. Using the nitric acid burette, add reagent nitric acid, one drop at a time; stir the sample continuously, until the violet or red color disappears. (The sample will probably then be pale yellow.)

4. Now add exactly 1 ml more of reagent nitric acid.

5. Fill the mercuric nitrate burette; let it drain down to zero.

6. Place the casserole under the mercuric nitrate burette; add reagent mercuric nitrate to the contents of the casserole. Stir continuously until a pale blue-violet color persists throughout the solution. (Add the mercuric nitrate at a fairly rapid rate at first; but add it very slowly—drop by drop—as the end point, indicated by the blue-violet color, is approached.)

7. Read the burette. Take the reading from the BOTTOM of the *meniscus* (the curved surface of the liquid column). Multiply the burette reading by the factor 0.25. For example, if the burette reading is 0.5, the chloride concentration is 0.125 epm ($0.5 \times 0.25 = 0.125$).

Testing The Density of Brine

Although the salt concentration of sea water is not always the same, the average is generally accepted as being $\frac{1}{32}$; that is, 1 pound of dissolved salts in 32 pounds of sea water. As sea water is vaporized in the distilling plant, the proportion of dissolved salts in the remaining solution (brine) becomes greater. The brine concentration (density) in the last-effect shell should be kept at $1.\frac{5}{32}$ that is, 1.5 pounds of dissolved salts in 32 pounds of brine.

The concentration of brine in the evaporator has a direct bearing on the quality of the fresh water distilled by the plant. Since the quantity of brine discharged overboard affects the operating conditions of the plant, it is desirable to keep the quantity of brine discharged and the density of the brine in the last-effect shell as nearly constant as possible. If the brine concentration is too low, there will be a loss in capacity and in economy; and it will be difficult to obtain proper feeding. If the brine

concentration is too high, there will be an increase in the rate of scaling of the evaporator tubes; and the quality of the distillate may be impaired. The brine concentration depends mainly on the quantity of brine pumped overboard and the quantity of fresh water being produced.

The density of the brine can be determined by means of a SALINOMETER. This instrument is calibrated in thirty-seconds. The instrument has four separate scales, which indicate the salinity of the brine at four different temperatures—110°, 115°, 120°, and 125° F. A salinometer and the pot used to hold samples of brine are illustrated in *Fireman,* NavPers 10520–A.

The brine concentration should be checked frequently during each watch, usually at intervals of one hour. Samples of the brine are usually obtained through a sampling cock at the brine-pump discharge. It is important to obtain a sample which is truly representative of the brine in the last-effect shell. The brine pump gland seal or brine dilution line should be secured in order to obtain a true sample. The temperature of the sample drawn into the sampling pot should agree closely with the reading of the thermometer on the last-effect shell. A difference of more than 3° or 4° usually indicates either faulty operation of the brine pump, or dilution of the brine between the last-effect shell and the sampling cock.

Under normal operating conditions, the density of the brine can be adjusted to $1.\frac{5}{32}$ by means of the hand-control valve located in the brine-overboard pump discharge line; the brine density should never exceed this amount. Care should be taken in opening and closing the hand-control valve; very small changes in position will cause the density of the brine to vary greatly.

MAINTENANCE OF LOW-PRESSURE PLANTS

The quality of the distillate produced by a distilling plant depends upon a number of factors, all of which are related, either directly or indirectly, to the amount of scale allowed to form within the tubes of the evaporator. Since scale has such an effect on the quality of the plant's

output, steps must be taken to retard its formation and to remove any scale that does form.

One of the first things to keep in mind is that the plant should be operated according to prescribed procedures. Improper operation leads to excessive scaling. Even under normal operating conditions, some scale will form on the distilling-plant evaporator tubes. The rate of scaling depends upon the concentration of suspended matter and carbonate salts which are present in the water used to feed the distilling plant. Scale deposits increase as the density of the brine in the last-effect shell increases. When the brine concentration is too high, there is an increase in the rate of scaling of the evaporator tubes; and the quality of the distillate may be impaired. In order to reduce the rate of scale formation and to remove scale which does form, the feed is treated and a means is provided for removing scale from the evaporator tubes.

Feed Treatment

To retard the formation of scale on evaporator tubes, a solution of boiler compound and cornstarch is continuously introduced into the evaporators. The purpose of the cornstarch is to minimize priming; the boiler compound combats tube scaling. (Additional information on feed treatment is provided in a more advanced training course for Enginemen.)

Chill Shocking

Even though proper feed treatment retards the formation of scale, some scale will always form on the tubes of an evaporator. Methods of removing the scale which forms in the tube nest of an evaporator include acid cleaning and mechanical cleaning. Acid cleaning permits scale removal without disassembly of the unit, but such cleaning must be accomplished by a naval shipyard or tender or under the supervision of shipyard or tender personnel. Mechanical cleaning may be accomplished by ship's personnel, but the tube nest must be removed from the evaporator for cleaning.

Scale may also be removed from the evaporator tubes of a low-pressure plant by a process referred to as CHILL SHOCKING. As the first step in this process, the brine is drained from all shells, and the shells are then reflooded by means of a hose line which is connected to a flushing pipe or flooding connection on each shell. This flooding chills the tube-nest bundles and causes some contraction of the tubes. Steam is then quickly admitted to the tubes; this causes some expansion of the tubes. The contraction and subsequent expansion causes the scale to break loose from the tubes.

If feed treatment with cornstarch and boiler compound is not used, the distilling plant should be chill-shocked daily. If feed treatment is used, daily chill shocking may be desirable; however, less frequent chill shocking may prove satisfactory.

During normal operation of the plant, a certain amount of chill shocking takes place automatically within the tubes of an evaporator. As temperatures in the evaporator shell and inside the evaporator tube nest vary, and when the plant is being started and secured, the tube bundle expands and contracts. This expansion and contraction causes a considerable amount of the scale on the tubes to loosen and to drop off in flakes, or scales. Such automatic cleaning of the tube surfaces, however, does not keep the surfaces sufficiently clean to provide adequate heat transfer; a positive means of scale cracking should be employed. The steps in such a chill-shocking process are:

1. Secure the steam supply to the first-effect tube nest, the tube-nest drain pump and its discharge valve, the condensate pump, and the fresh-water pump.

2. Open the emergency circulating-water overboard valve at the outlet from the air-ejector condenser; secure the first-effect feed valve.

3. Open wide all interstage feed valves. In plants which have shell-drain or pump-out lines connected to the brine-pump suction, unlock and open wide the valves in these lines.

4. Pump out the brine from all evaporator shells.

5. Connect a hose line to the flushing pipe or the flooding connection.

6. Open the hose (water-supply) valve and spray or flood the evaporator shells until the tubes in all evaporator shells are fully submerged.

7. Secure the hose valve and again pump out all evaporator shells.

8. Flood all shells again until the tubes in all shells are submerged. The purpose of this second flooding is to further lower the tube-bundle temperature.

9. When the tubes are fully submerged, secure the hose valve and quickly open the steam-supply valve to the first-effect tube nest. The flow of steam, which will be restricted somewhat by the orifice, if one is installed, should be increased by loading the weight-loaded regulating valve so that the pressure above the orifice is increased to about 10 psig. As soon as the water starts to boil in the first-effect shell, remove the extra weights from the regulating valve and bring the pressure back to normal.

After the chill shocking process has been completed, place the plant back in normal operation by following the prescribed operating procedures.

When the boiler compound-cornstarch feed treatment is not used, chill shocking loosens fairly large particles of scale. These particles must be removed periodically (usually, about once a week). When the feed treatment is properly used, there is practically no accumulation of scale at the bottom of the evaporators. Removal of scale once a month, in this case, will probably be adequate.

To remove scale from the bottom of the evaporator shells, secure the plant temporarily; remove the cleanout plates at the bottom of the evaporator shells; and rake out the scale.

NEW DESIGNS IN LP DISTILLING PLANTS

Some of the newer ships in the Navy are being equipped with low-pressure distilling plants which differ radically from the more familiar, submerged-tube type plant pre-

viously discussed. There are two types of these new low-pressure plants: the vertical-basket type and the flash type.

Vertical Basket-Type Plant

This type of distilling plant comprises two-effect evaporators (or evaporators with a greater number of effects), a distiller condenser, vapor feed heaters, air ejectors and after condensers, and a distillate cooler. The only difference between this type of distilling plant and the conventional, submerged-tube type is in the evaporators. In the newer type, each evaporator consists of a vertical shell in which a deeply corrugated, vertical basket is installed. (In some installations, more than one basket may be installed.) Low-pressure steam is admitted to the inside of the first-effect basket; feed water is boiled in the space between the outside of the basket and the shell. The vapor from the boiling feed water passes through centrifugal-type vapor separators and the vapor feed heater to the inside of the second-effect basket. This vapor boils the brine from the first-effect in addition to a certain amount of feed water in the space between the shell and the basket. The vapor thus formed passes, through separators, to the subsequent effects or, in the case of a two-effect evaporator, into the distiller condenser.

Flash-Type Plant

The low-pressure, flash-type distilling plant includes two or more stages, each of which is composed of a flash chamber, a feed box, a vapor separator, and a stage condenser. In addition, the plant contains a two- or three-stage air ejector, an after condenser, and a feed-water heater. The feed water passes through the tubes of the stage condensers in series, then through the tubes of the after condenser, and finally through the tubes of the feed water heater. In each heat exchanger, heat is transferred to the feed water; the final heating is done by low-pressure steam admitted to the shell of the feed-water heater. From this heater, the feed water is passed to the first-stage feed box; it comes out, through orifices, into the

flash chamber. Part of the heated feed water flashes to vapor under the vacuum in the flash chamber. The remainder of the feed water passes, through a loop seal, to the feed box of the next stage. This flashing process is repeated in subsequent stages; the brine remaining is removed by the brine-overboard pump.

Vapor formed in each stage passes, through a vapor separator, into the stage condenser; here it is condensed to distillate. The distillate from each stage passes through a loop seal on its way to the condenser of the next stage. The distillate is removed from the final stage by the distillate pump. For detailed information about these two, new-type distilling plants, refer to the manufacturers' instruction books: NavShips 358–0307 for the low-pressure, vertical-basket type evaporator; and NavShips 358–0324 for the low-pressure, flash-type evaporator.

RADIOLOGICAL CONTAMINATION AND RADIAC INSTRUMENTS

The development of atomic weapons has progressed to a point where we are no longer limited to atomic bombs. The atomic cannon is a reality; atomic energy is being used in submarine engines; additional military applications of atomic energy are beyond the planning stage. At least one communist nation is known to manufacture atomic weapons. Under the existing international situation, there is always the possibility of an atomic attack. The threat of such an attack makes it essential that you be familiar with some of the facts concerning atomic, or radiological, warfare. Information dealing with how to protect yourself, your shipmates, and your ship in the event of an atomic attack is provided in a basic Navy Training Course, *Atomic Warfare Defense,* NavPers 10097. This course will serve as an important source of information on what to expect and what to do in the event you are subjected to an atomic attack.

One of the effects of an atomic attack would be nuclear radiation. The blast and thermal effects of an atomic explosion would cause extensive damage to materials; nu-

clear radiation, however, does not affect materials in any visible manner. Nuclear radiation is chiefly a hazard to personnel.

The strong, penetrating, radioactive rays which are released by an atomic explosion may cause casualties if contamination is sufficiently great. The rays tend to destroy the body cells, especially the blood-forming cells. The extent to which nuclear radiation affects the body depends upon the length of time of exposure to radioactive materials. As an EN3 will be required to be able to use instruments which indicate the degree of RADIOLOGICAL CONTAMINATION present in drinking water.

In the event of an atomic attack, the sea water in the area around the explosion will be contaminated with radioactive particles. If a ship enters an area where the sea water has been contaminated in this way, there is a possibility that radioactive particles will find their way into the ship's drinking-water supply; the distilling plant must, therefore, be secured immediately. If sufficient concentration of radioactive particles is present, use of contaminated distillate may be harmful to personnel.

Nuclear radiation cannot be detected by any of the five natural senses. Special instruments and devices which will detect the presence of nuclear radiation have been developed. These instruments and devices not only detect radioactivity; they also indicate the kind of radiation and the extent of contamination. Devices used for these purposes are known as RADIAC INSTRUMENTS.

As an EN3, you will be required to use radiac instruments and to perform monitoring operations, for the purpose of determining the extent of radioactive contamination, on intake lines and distilling plants. Chapter 4 in *Atomic Warfare Defense,* NavPers 10097, provides information on radiac instruments and on their use in detecting nuclear radiation.

QUIZ

1. What are the basic units of a steam distilling plant?
2. Are low- or high-pressure steam distilling plants more common aboard ship?
3. How many stages of evaporation are there in plants which have a capacity of 12,000 gpd or less?
4. Steam plants in which evaporation takes place in three stages are generally referred to as what type of plant?
5. From what does the condenser circulating-water pump take suction?
6. What is used as feed for the first-effect evaporator?
7. How does the manner in which feed is delivered to the first-effect evaporator differ in double- and triple-effect plants?
8. By what means are the particles of feed water removed from the vapor?
9. What causes feed flow between the first and second effects?
10. What is the purpose of the air ejector?
11. What is the maximum allowable chloride content in distilled water which is used for drinking purposes?
12. What brine concentration should be maintained in the brine-overboard discharge?
13. Explain briefly how chill shocking removes scale from evaporator tubes.
14. Name three types (on the basis of design) of low-pressure, steam distilling plants which are used aboard ship.

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

THE ENGINEMAN

1. As ratings.
2. Diesel Engineman (END); and Gasoline Engineman (ENG).
3. General service; emergency service.
4. Emergency service.
5. The work required of an emergency service rating is more specialized than that of the general service rating.
6. A rate designates a level of advancement and a pay grade; a rating designates a Navy occupation.
7. Practical factors and examination subjects.
8. Those qualifications which indicate the jobs that an Engineman must perform satisfactorily in order to advance.
9. A qualification which indicates the subject matter you must know in order to perform a related job (practical factor).
10. By actual experience and by studying.
11. Your Information and Education Officer.
12. Be sure that the publication is the most recent, revised edition available.

CHAPTER 2

THE ENGINES

1. The sequence of events that takes place in the cylinder of an engine for each power impulse to the crankshaft.
2. Intake of air, compression of air, injection of fuel, ignition and combustion of fuel-air charge, expansion of gases, and removal or exhaust of waste.
3. In gasoline engines, the intake and compression events involve fuel in addition to air.
4. No.
5. Either two or four, depending upon engine design.
6. A stroke signifies the piston's motion between limits of travel, while an event is an action which takes place during a stroke.
7. Intake and exhaust.
8. Top dead center (TDC) and bottom dead center (BDC).
9. So that the intake or scavenging air will aid in clearing the cylinder of waste gases.

10. Intake starts several degrees before TDC in a 4-stroke cycle engine, while the corresponding event (scavenging) in a 2-stroke cycle engine occurs several degrees before BDC.
11. 2-stroke cycle engine.
12. Its volume decreases and its pressure and temperature increase.
13. Combustion takes place with no piston movement; thus, the volume of the gases remains constant throughout the combustion phase.
14. In the true Diesel cycle, combustion takes place at constant pressure as compared to the constant volume combustion of the Otto cycle.
15. It increases.
16. The combustion curve indicates that there is piston movement since combustion starts before and ends after TDC; thus, a slight decrease and then a slight increase of volume during the combustion phase.
17. Part of the phase takes place at constant volume.
18. Since the events in the operating cycle of a 2-stroke cycle engine take place during two piston strokes, the intake and exhaust events occur during a relatively short interval of time near BDC and do not involve full piston strokes as in the case of 4-stroke cycle engines.
19. The number of degrees that a crank on the lower shaft of an opposed-piston engine travels in advance of a corresponding crank on the upper shaft.
20. When the position of the upper shaft crank is the same number of degrees before IDC as the lower shaft crank is past IDC.
21. Exhaust ports.
22. Lower crankshaft.
23. Two-stroke cycle double-acting engine.
24. Each type engine produces useful power through a process in which gas is compressed, a fuel-air mixture is burned, and the gases of combustion expand.
25. Ignition. (Ignition is necessary only for starting.)
26. Part of the intake air.
27. Gas flow which, in turn, is governed by the amount of fuel burned.

CHAPTER 3

PRINCIPAL STATIONARY PARTS OF AN ENGINE

1. To maintain the moving parts of the engine in their proper relative position.
2. Ample strength, low weight, minimum size, and simplicity of design.
3. Frame.
4. Block.

5. En bloc type blocks are cast in one piece while blocks of most large engines are constructed of welded steel forgings and plates.
6. Liners.
7. Crankcase.
8. The housing may be an integral part of the block or it may be a separate engine part.
9. To add rigidity to the block and to provide a surface for attaching engine parts and accessories.
10. Some access openings and covers, designed to act as safety devices, serve as escape vents for excess pressure which may develop within the crankcase.
11. Accurate machining of the mating surfaces.
12. Because they can be replaced or reconditioned as a single unit when excessive wear occurs.
13. To provide a surface which is more resistant to wear and which aids in maintaining a lubricating film.
14. Whether the coolant does or does not come in direct contact with the liner.
15. Enlarge cylinder bore.
16. The liner and block; or a separate jacket which fits in the block or frame.
17. The expansion and contraction of the liner.
18. To prevent the formation of a ridge or lip on the liner surface at the upper limit of firing ring travel.
19. Opposed-piston engines.
20. Parts essential to engine operation may be mounted in or attached to a cylinder head.
21. Design and material must be such that the head will withstand the rapid changes of temperature and pressure taking place in the cylinder, and the stress created by being bolted to the block.
22. Studs and gaskets.
23. To prevent the stud from unscrewing when the stud nut is removed.
24. Compressibility.
25. Misalinement between units is less likely to occur.
26. Rigid and flexible.
27. Isolators are designed to absorb forces of relatively minor vibrations originating within the engine while absorbers are designed to protect the engine from severe shock loads imposed by external forces.

CHAPTER 4

PRINCIPAL MOVING PARTS OF AN ENGINE

1. Reciprocating parts; reciprocating and rotating parts; and rotating parts.
2. When compared to aluminum, cast iron gives longer service with less wear, can be fitted to closer clearances, and is less subject to distortion. The principal advantages aluminum has over cast iron are its lighter weight and higher conductivity.
3. To allow for expansion of the metal at the combustion end of the piston.
4. To allow room for parts which protrude into the combustion space.
5. Plain (smooth), slotted (split), and knurled.
6. They serve as mounting places for the bearings which support the wrist pin, or as points of attachment for the pins.
7. Seal the cylinder, distribute and control lubricating oil in the cylinder, and transfer heat from the piston.
8. Transfer of heat from the piston to the cylinder wall.
9. The action of the confined gases.
10. Hot gases have been escaping from the combustion space.
11. So that the gaps of successive rings are on alternate sides of the piston.
12. Control rings.
13. They prevent excessive amounts of oil from flowing to the compression rings.
14. Ring expander.
15. Forces created by combustion; and side thrust created by the change from reciprocating to reciprocating and rotary motion.
16. It alternates from side to side.
17. A pin may be fastened rigidly into the piston bosses, clamped to the end of the connecting rod, or held in place by separate devices located in the piston bosses.
18. Sleeve bushing.
19. Full-floating pins.
20. Bronze.
21. Shell type and roller type.
22. Shell type.
23. The shells for a fork-and-blade rod have a bearing surface on both the inner and outer surfaces; the shells for a conventional rod have a bearing surface on the inner surface only.
24. Padded type.
25. By retainer rings.
26. Crosshead type.
27. It guides the piston rod along the vertical axis of the cylinder and absorbs side thrust.

28. In a cylinder fitted with a trunk type piston, the side thrust alternates from side to side and is absorbed by the cylinder wall. In the cylinder of a double-acting engine, side thrust acts in only one direction and is absorbed by the crosshead assembly.
29. The gibs receive side thrust when the direction of the thrust is reversed, as in a reversible double-acting engine.
30. The flow of oil through the rod and piston.
31. Hollow construction reduces weight and provides passages for lubricating oil.
32. Counterweights or dampers.
33. Yes. No.
34. In a 2-stroke cycle engine, load is always placed on the lower half of the bearing; in a 4-stroke cycle engine, the load is applied first on one bearing shell and then on the other.
35. Bronze or steel back, bonded with high-lead-content bearing material; steel back, with an intermediate layer of bronze to which is bonded a bearing surface of lead-base or tin-base babbitt; and, steel back with copper-lead bearing surface.
36. It serves as a protective coating against corrosion.
37. They must be replaced.

CHAPTER 5
ENGINE AIR SYSTEMS

1. Increasing the flow of air into engine cylinders and clearing the cylinders of waste gases.
2. Bottom dead center.
3. Supercharging.
4. Both open.
5. (a) 1/8; (b) 1/120.
6. Before TDC.
7. Upstroke.
8. Two-stroke cycle.
9. It aids in cooling the parts heated by combustion.
10. The mesh of the viscous type is wet with oil.
11. Over the oil.
12. The inertia of the particles.
13. To deliver a large volume of air at low pressure.
14. Positive displacement type.
15. Centrifugal type.
16. Yes.
17. The source may be either the engine lubricating system or an independent turbocharger lubricating system.
18. It is cleaned, silenced, and compressed.
19. Air box, receiver, or header.

20. Condensation of the vapors from the air charge and lubricating oil which may blow into the box when the ports are uncovered by the piston.
21. The passage is not an integral part of the block in a 4-stroke cycle engine.
22. Four-stroke cycle engine.
23. The sodium aids in cooling the valve.
24. To relieve cylinder pressure when it exceeds a safe operating limit.
25. The use of cooling water; and the use of insulation.
26. Internal baffles and water.
27. Circulating water is used only for cooling in silencers of the dry type, and for both cooling and silencing in silencers of the wet type.
28. Cleaner, blower, air box, ports, cylinders, valves, manifold exhaust pipe, muffler, tail pipe.
29. Two-stroke cycle engine. In a 2-stroke cycle engine, only intake air passes through the blower; in a supercharged 4-stroke cycle engine, both intake air and exhaust gases pass through sections of the turbocharger. Also, air boxes are found only on 2-stroke cycle engines.

CHAPTER 6
OPERATING MECHANISMS FOR ENGINE PARTS AND ACCESSORIES

1. Camshaft drive.
2. Gear, chain, and belt.
3. Gear.
4. Valve-actuating mechanism and accessories.
5. No.
6. Three.
7. To counterbalance oscillatory impulses developed by the weighted camshaft and within the engine.
8. Blower drive shaft, upper rotor drive gear, lower rotor driven gear, lower rotor shaft, and coupling.
9. It transmits power to the fuel injector.
10. By push rods.
11. Fuel pump, lubricating oil pump, governor, and tachometer.
12. In the GM 16-278A, push rods are not necessary, since the cam lobes come in direct contact with the rollers of the rocker arms.
13. Valve bridge.
14. To keep bridge tension off the valve stems until the rocker arm actuates the bridge.

15. It is driven by the crankshaft through an intermediate shaft.
16. Camshaft drive, blower drive, and accessory drive. The first is a chain drive and the other two are gear-type mechanisms.
17. Fuel injection pumps.
18. The upper crankshaft of the engine.
19. Tappet assemblies.
20. Lower crankshaft of the engine.
21. To permit camshaft timing adjustment by slight rotation of the camshaft drive gear without moving the sprocket.
22. Camshaft drive gear and camshaft driven gear.
23. Engine camshaft, related to the intake and exhaust systems; fuel injector camshaft, related to the fuel system; and pilot valve camshaft, related to the air-starting system.
24. To provide positions for two directions of engine operation—ahead and astern.
25. Double arm rocker.
26. The rocker arms of the Packard engines are of the end-fulcrum type; the rocker arms of the other engines are of the center-fulcrum type.
27. The supercharger of the Packard gasoline engine is driven by a gear-type mechanism; and the supercharger of the GSB-8 is exhaust-gas driven.
28. Helical, bevel, and worm.
29. Roller.

CHAPTER 7

ENGINE FUELS AND FUEL SYSTEMS

1. Fuel and air are admitted separately to the cylinders of a Diesel engine; and as a mixture to the cylinders of a gasoline engine.
2. By compression of intake air.
3. Diesel.
4. Because the heat caused by compression is not great enough to cause self-ignition of the combustible mixture.
5. The higher the pressure, the greater the power output.
6. The characteristics of the fuel used.
7. Engine speed, type of fuel, and compression ratio.
8. After.
9. No.
10. Because combustion takes place in larger space.
11. The rate and amount of fuel injected determine maximum pressure.
12. Motion of air within the combustion space.
13. To bring sufficient air in contact with injected fuel particles to ensure complete combustion.
14. Piston crown and cylinder head.
15. Open chambers have no auxiliary combustion chambers.

16. The conditioning of all or part of the fuel, by partial burning, before it enters the main combustion space.
17. To aid in creating the turbulence necessary for the proper mixing of air and fuel.
18. Main combustion space.
19. Volatility.
20. The formation of vapors in the fuel system which block or restrict the flow of fuel to the carburetor.
21. Improper fuel distribution and crankcase dilution.
22. Loss of power and undesirable combustion noises.
23. During the final phase; start of second phase.
24. Anything which increases excessively the temperature or pressure of the unburned mixture in the combustion space.
25. Compression ratio.
26. The interval of time between the injection and the ignition of fuel.
27. The temperature and pressure of the compressed air in the combustion space, the average size of the injected fuel particles, and the amount of turbulence in the combustion space.
28. Fuels with a low volatility.

CHAPTER 8
ENGINE IGNITION SYSTEMS

1. The source of electrical energy.
2. To energize the secondary, or high-voltage, winding of the ignition coil.
3. To serve as a conductor for the magnetic field.
4. The coil operates on the principle of electromagnetic induction; in other words, the coil depends on the inductive effect of the magnetism produced by the low voltage in the primary winding to produce high voltage in the secondary winding.
5. To act as a switch, opening and closing the primary circuit.
6. To provide a single spark to each cylinder; and to provide two sparks simultaneously to each cylinder.
7. It is momentarily increased because a voltage is also induced in the primary circuit when the breaker points open and the magnetic field collapses.
8. The condenser.
9. Rotor (distributing arm) and cap (head).
10. To close the secondary circuit, so that current from the high-voltage side of the coil will flow to the proper spark plug.
11. So that half of the spark plugs will fire during each revolution of the crankshaft.
12. Lobes on the breaker-assembly cam.
13. Advanced.
14. Retard.

15. Centrifugal force and vacuum.
16. The action of springs.
17. Centrifugal
18. So that proper spark-control is provided under all conditions of speed and load.
19. Spring-loaded diaphragm.
20. On the carburetor side.
21. The material used in the insulator or core.
22. The amount of insulator exposed to the combustion gases.
23. By absorbing and grounding the high-frequency current given off by the parts of the ignition system.
24. Armature wound and inductor type.
25. No.
26. In the primary circuit.
27. In the low-voltage magneto system, the distributing mechanism is located in the primary circuit; and it is located in the secondary circuit in the battery-ignition and high-voltage magneto-ignition systems.
28. Shorter high-voltage leads, less electrical loss, and problems of a less serious nature in insulation and shielding.
29. Either from a booster coil-and-battery circuit or from the magneto by increasing its speed with an impulse mechanism.
30. No.
31. In a battery ignition system, the safety device opens the primary circuit to stop the flow of current; in a magneto-ignition system, the primary circuit is grounded.

CHAPTER 9

ENGINE LUBRICANTS

1. To prevent metal-to-metal contact; to form a seal between the piston rings and the cylinder; to aid in engine cooling; and to aid in preventing and removing sludge formations.
2. By forming a film which prevents direct contact between moving metal surfaces.
3. To prevent blow-by of gases.
4. Bearings, journals, and pistons.
5. To the mass of oil in the sump or to the water in the cooling system.
6. Viscosity.
7. Operating temperatures, speeds, pressures, and bearing clearances.
8. The oil's ability to remove or to prevent the accumulation of carbon deposits.
9. To identify the use and viscosity of each oil.

10. The tendency of the oil to stick to metal surfaces and the natural detergent property of the oil are improved by additives; additives also inhibit oxidation.
11. A mixture of additive- and mineral-type oils.
12. Water or partially burned fuel in the lubricating oil.
13. No.
14. The difference in the specific gravities of the sediment, water, and oil.
15. When used as a separator, the purifier separates oil from water and sediment. When used as a clarifier, a purifier separates oil from sediment only.
16. The moisture content of the oil being purified.
17. The design of the rotating elements.
18. Disk type.
19. To rotate the oil at the speed at which the bowl is rotating.
20. When it is being used as a separator with 9000 series oil.
21. Oil will be lost through the water-discharge ports.
22. The viscosity of the oil.
23. Temperature.
24. Purification is improved, because the reduction in the pressure increases the length of time the oil is subjected to centrifugal force.
25. The specific gravity of the oil.
26. By observing the clarity of the purified oil and the amount of oil in the separated water.
27. A lime-soap.
28. Because of its abrasive characteristic.

CHAPTER 10
ENGINE LUBRICATING OIL SYSTEMS

1. Positive-displacement rotary-gear pump.
2. Pressure-regulating valve; pressure-relief valve.
3. By recirculating excess oil from the pump discharge back to the pump intake or by discharging the excess oil directly to the oil sump.
4. In order that one element can be bypassed and removed for cleaning without interruption to the flow of oil to the engine.
5. No, because strainers of this type are provided with pressure-relief valves through which all oil may be bypassed to the engine.
6. Edge-wound metal ribbon; edge-type disks.
7. By manual rotation of the element against metallic scrapers, which remove the material caught by the element.

8. On the suction, or intake, side.
9. Fuller's earth removes the compounds (detergents) from additive-type oils.
10. Shunt, sump, and bypass.
11. Shunt.
12. In a sump-type filtering system, the filter is placed in a separate system in which oil is circulated by a motor-driven pump; the filter in a shunt-type system is located in the main lubricating-oil system.
13. Sump-type filtering system.
14. Sump, pump, cooler, and strainer.
15. Sump-type and bypass-type.
16. The size of the piping, and an orifice.
17. Sump tank, pump, strainer, filter, and cooler.
18. (a) Through drilled passages in the connecting rod.
    (b) By nozzles connected to an oil manifold.
19. Manifold (also called galley, or header).
20. An auxiliary pump is used if the lubricating-oil pump fails; it may also be used to circulate oil through the system when the engine is not operating.
21. Crankpin bearings usually receive oil from the main bearings, through drilled passages in the crankshaft.
22. By oil, mixed with the gasoline, which enters the engine with the fuel-air mixture.
23. An explosive mixture may accumulate; the lubricating oil may be diluted; corrosion may take place within the crankcase; and the lubricating oil may become emulsified.
24. Because the unburned fuel which might blow-by the compression rings is trapped in the intake ports and is forced back into the combustion space by the scavenging air when the intake ports are uncovered by the piston.
25. By a fine-wire screen device which separates the oil from the ventilating air and causes the oil to drain back to the oil supply.
26. They are forced into the combustion space and are either burned or discharged with the exhaust.
27. By causing excess heat, which vaporizes the oil; and by causing sparks, which may ignite the explosive mixture.
28. The oil pressure gage.
29. Because the flash point of the fuel is lower than that of lubricating oil, fuel-diluted oil tends to form an explosive mixture more rapidly than does lubricating oil, which is not diluted.

CHAPTER 11

ENGINE COOLING SYSTEMS

1. To maintain adequate lubrication; to prevent excessive variations in dimensions of parts; and to retain strength of metals.
2. Excess heat may reduce viscosity to a point where the oil film between parts may be destroyed. Also, heat causes oxidation of the oil and the formation of sludge.
3. An excessively low engine temperature may: cause corrosive gases to condense on the cylinder walls; increase ignition lag, causing detonation; and cause condensation, which leads to the formation of acid and sludge in the lubricating oil.
4. Inadequate cooling may allow an engine to overheat to the extent that closely fitted parts will seize because of the expansion of parts and the reduction of clearance.
5. Sea chest or scoop, strainer, sea valves, pump, lubricating-oil cooler, engine passages and jackets, exhaust-silencer water jackets, and overboard outlet.
6. No.
7. Lubricating oil and exhaust gases.
8. The fresh-water cooler is located outside of the hull, below the water line, in direct contact with the sea water.
9. Pump (discharge), engine passages, fresh-water cooler, lubricating-oil cooler (when applicable), and pump (suction).
10. Sea chest, strainer, sea valves, fresh-water cooler, lubricating-oil cooler (when applicable), exhaust cooling passages, and overboard outlets.
11. To be used in the event of attached-pump failure and to provide a means of cooling after the engine has been secured.
12. Fresh- and sea-water pumps may differ in type, size, and capacity.
13. Centrifugal, gear, and rotary (vane).
14. Centrifugal.
15. Gears, pulley and V-belt, and coupling.
16. Fresh water, lubricating oil, and air (in some cases).
17. Shell-and-tube, strut-tube, and plate-tube.
18. The tube bundle (bank, nest) and the shell.
19. The cooled liquid generally flows through the tubes; the cooling liquid generally flows around the tubes.
20. To allow for expansion of the tube bundle.
21. That the direction of liquid flow in the tubes is opposite to that in the shell.
22. Smaller.
23. The shell-and-tube cooler.

24. "Struts" increase the inside and outside contact surfaces of the tube, create turbulence in the liquid flowing through the tube, and increase the structural strength of the tube.
25. Plate-tube cooler.
26. A fresh-water cooler which is located outside the hull, below the water line, in direct contact with the sea water.
27. Zincs.
28. No. Zincs are installed to provide a replaceable surface for the attack of galvanic action.
29. Pencil and plate.
30. Cylinder-head passages.
31. GM 16–278A: Pump, water manifold, liner passages, head passages, exhaust passages, cooler, and pump.
    FM 38D: Pump, exhaust passages, liner passages, water header, cooler, pump.
32. The tank provides a place where water may be added to the system, and a space to accommodate variations in the volume of the water.

CHAPTER 12

DRIVE MECHANISMS

(Transmission of Engine Power)

1. The driven gear.
2. The speed of the driven unit is one-third that of the driving unit.
3. 2/1.
4. Decrease.
5. No.
6. (a) To reduce or increase the shaft speed of the driven unit, compared to the speed of the driving unit; (b) to provide a means of reversing the direction of rotation of the driven shaft; and (c) to permit quick-disconnect of the driving unit and the driven unit.
7. To reduce propeller speed to the most efficient operating level.
8. By reversing the direction of engine operation; and by the use of reverse gears.
9. The generator and the motor.
10. Direct.
11. By reversing the flow of current to the motor, which, in turn, reverses the direction of rotation of the rotor of the motor and of the propeller.
12. (c) Between the motor and the propeller.
13. Flexible couplings absorb vibration and permit some misalignment of the driving and driven units.

14. The engine lubricating-oil system; an independent oil-system.
15. By gravity; by a scavenging system.
16. That the oil level in the gear case is too high.

CHAPTER 13

ENGINE OPERATING PROCEDURES—GENERAL

1. The lubricating oil pump(s) must be in operation.
2. One type of device is used to heat the intake air or a portion of the cylinder charge; another type is used to supply an auxiliary, low-ignition-temperature fuel to the cylinders during the starting period.
3. Electric, and fuel oil.
4. Ether.
5. Because of uneven rates of expansion of engine parts and inadequate lubrication.
6. The lubricating oil may be diluted; fuel consumption may be increased.
7. Excessive temperatures, excessive pressures, and smoky exhaust.
8. (1) Mechanical oilers, if provided, should be checked frequently for proper feed; (2) the oil level in the sump should be checked frequently and oil should be added, as necessary; (3) purifiers, if provided, should be operated in accordance with prescribed instructions; (4) cleaning handles of all oil strainers should be rotated at recommended intervals; and (5) the viscosity of the oil should be checked at least once each day.
9. (1) Salt-water cooling system; (2) fresh-water cooling system; (3) lubricating-oil system.
10. By regulating the amount of water discharged, by the pump, into the engine; by regulating the amount of water which passes through the cooler.
11. In the fresh-water discharge line from the engine.
12. To any range of engine speed during which excessive vibration is created in the engine.
13. So that the operating condition of the device can be checked.
14. When provided, independent water-pumps and lubricating-oil pumps are operated for a short period of time.
15. The engine should be stopped, and the cause of the popping should be determined and remedied.
16. Steps must be taken to ensure that there is no gasoline vapor in the engineroom or in other spaces. These steps will vary, depending on the installation, they may include, however, such items as operating the engineroom exhaust-blower and opening the engine head, or casing, to permit free circulation of air.

17. So that the oil level in the crankcase can be checked when the engine is not operating and when the boat is under way.
18. The tank with the highest level should be used, so that the tanks can be kept as nearly balanced as possible.
19. So that the starting motor will not be overheated and damaged.
20. The carburetor and the intake manifold may be heated by wrapping them in rags and then applying boiling water to the rags.
21. The coil, which may overheat; and the points, which may burn.
22. Less time is required for completing the warm-up; the tendency of the spark plugs to foul is reduced.

CHAPTER 14

MAINTENANCE OF ENGINE SYSTEMS

1. The inspection and repair of the major engine components, one at a time, until the entire engine has been progressively inspected and overhauled during the recommended period of time between major overhauls.
2. (b) When the strainer is not in use.
3. So that the oil may be checked for metal particles which are an indication of trouble inside the engine.
4. Ruptures.
5. Only in emergencies, when new elements are not available and the engine must be operated.
6. Zincs which are more than one-half deteriorated should be replaced.
7. Mechanical cleaning, used in cleaning shell-and-tube coolers; chemical cleaning, used in cleaning coolers of the radiator and plate types.
8. Faulty operation of the strainer; improper lubrication of the water pump; and a leaking element.
9. Air lance, water lance, bristle brush (rotating), and rubber plugs.
10. Boiler compound and sodium dichromate.
11. Slight alkalinity counteracts acid corrosion.
12. Alkalinity, sodium chromate, and chloride tests.
13. The water-treatment solution contains insufficient boiler compound.
14. The parts within the cooling system may corrode.
15. (a) Sodium chromate; (b) chloride; (c) alkalinity.

CHAPTER 15

MAINTENANCE OF ENGINE PUMPS AND VALVES

1. Centrifugal.
2. So that the pumped liquid may be recirculated to the suction side of the pump, when the amount of liquid being pumped is greater than the amount required.
3. (a) Plunger-type pumps; and (b) diaphragm-type pumps.
4. A clogged strainer.
5. (a) Noise of breakage; (b) a rise in cooling-water temperature; and (c) loss of discharge pressure.
6. They should be staggered.
7. To provide lubrication for the packing, and to carry heat away from the packing gland.
8. Heat generated by friction within the pump may expand the impeller so much that it will seize the casing.
9. The seat and the disk should be spotted-in.
10. By spotting-in the disk to the seat.
11. Only by machining.
12. Only when the valve seat contains irregularities that cannot be satisfactorily removed by grinding-in.
13. A disk should be spotted-in and ground-in to the seat.
14. Four.
15. Set up on the gland; if this fails to stop the leakage, repack the stuffing box.
16. To prevent the packing from folding back when the gland is tightened.
17. Make sure that the valve is either wide open or fully closed.

CHAPTER 16

MISCELLANEOUS AUXILIARY EQUIPMENT

1. The volume of air displaced by first-stage piston(s) on compression strokes.
2. Three.
3. The difference in pressure between the air within the cylinder and the air on the external surfaces of the intake and discharge valves.
4. A check valve installed at the end of each cylinder feed-line.
5. By gravity.
6. Valves are arranged so that the quantity of cooling water passing through the oil cooler may be regulated without changing the quantity of water circulating through the rest of the system.
7. They cool the compressed air, between stages of compression.
8. To remove water and oil from the compressed air.

9. No.
10. Constant-speed control.
11. Pressure.
12. The operator can set the controls so that the compressor will operate under either start-stop control or constant-speed control.
13. Air-intake filter; first-stage compressing element(s); first-stage intercooler; second-stage compressing element; second-stage intercooler; third-stage compressing element; aftercooler; and air receiver.
14. Fumes may collect and cause an explosion in the compressor or in the receiver.
15. (1) Dust-laden intake air; (2) oil vapor in the compressor or in the receiver; and (3) abnormally high temperature resulting from leaky or dirty air-valves.
16. The compressor should be secured.
17. The valves should be closed.
18. Air leakage, through a poor connection, into the suction side.
19. The lubricating oil is mixed with the engine fuel.
20. That air has been exhausted from the pump and that water has entered the pump.
21. Irregular engine operation; lowered position of the float-pin in the carburetor bowl.

CHAPTER 17

OPERATING SHIPBOARD REFRIGERATION AND AIR CONDITIONING SYSTEMS

1. The condenser, receiver, and cooling coil.
2. In the main liquid-line, just ahead of the dehydrator.
3. By use of a dehydrator.
4. By viewing the liquid as it flows through the sight-flow indicator.
5. Thermostatic expansion valve.
6. To prevent liquid refrigerant in the suction line from entering the compressor; and to prevent the liquid in the liquid line from flashing into gas.
7. One scale indicates refrigerant pressure; the other scale indicates the corresponding temperatures of the refrigerant.
8. Higher.
9. The cooling coil and the compressor.
10. Either water or air.
11. The sea; and the ship's fire and flushing main.
12. The refrigerant pressure in the compressor-discharge line.
13. Excessive refrigerant-condensing pressures will develop; the cooling capacity of the unit will be decreased; and the compressor motor may become overloaded.

14. The valve will be deenergized and will close, thereby stopping the flow of liquid refrigerant.
15. The valve is actuated electrically through a thermostatically-controlled switch which is responsive to temperature changes in the space being cooled.
16. To control the starting and stopping of the compressor.
17. It is connected to the compressor-discharge line.
18. Only when the high-pressure cutout switch fails to operate properly or when this switch is improperly adjusted.
19. The high-pressure cutout switch.
20. Open.
21. Manual.
22. When the momentary-contact start-switch is closed.
23. To enable the operator to determine whether or not the compressor is operating properly.
24. The suction pressure and the pressure in the compressor crank-case.
25. By manipulation of a valve in the overboard line from the condenser.
26. The compressor should be stopped with the manual control.
27. Increasing the range between the cutin and cutout points of the low-pressure control switch; reducing the capacity of the compressor.
28. Hourly.
29. Any deviation from recommended temperatures and pressures; an abnormal lubricating-oil level in the compressor; and unusual noises within the compressor.
30. Goggles should be worn to protect the eyes from the Freon-12.

CHAPTER 18

VAPOR COMPRESSION DISTILLING UNITS

1. Vapor compression and steam.
2. Evaporator, compressor, and heat exchanger.
3. The steam chest and the vapor separator.
4. A baffle arrangement within the steam chest causes the non-condensable gases to flow out through a vent.
5. Electric heaters.
6. The brine flows to the heat exchanger, where the heat of the brine is transferred to the incoming feed.
7. From 1/2 to 2/3.
8. The vapor separator.
9. To provide a means of maintaining proper belt tension.
10. By slinger rings.
11. The exchanger warms the sea-water feed with heat removed from the condensate and the brine.
12. Feed, vent, condensate, and brine-overflow.

13. Feed, condensate, and brine-overflow.
14. The valve permits the compressor to discharge directly into the vapor separator when the unit is being started.
15. The steam trap.
16. A rotameter measures and indicates the rate of flow.
17. Either a manometer or a compound pressure gage.
18. By forming approximately a pound of steam in the steam chest as a pound of compressed, saturated steam condenses on the outside of the tubes.

CHAPTER 19

LOW-PRESSURE STEAM DISTILLING PLANTS

1. An evaporator (boiler); and a condenser (distiller).
2. Low-pressure plants.
3. Two.
4. Triple-effect.
5. The sea.
6. Part of the sea water from the circulating-water circuit.
7. The back-pressure valve in the circulating-water discharge line of a double-effect plant is set so as to maintain sufficient head to deliver feed to the evaporator. In triple-effect plants, pumps are used to deliver the evaporator feed.
8. By a series of baffles above the surface of the water in the evaporator shell, and by additional baffles in the first-effect vapor separator.
9. Pressure differential between the two effects.
10. To remove noncondensable gases from the condenser.
11. 0.065 emp.
12. 1.5/32.
13. The tubes are chilled and heated; the resulting contraction and expansion causes the scale to break loose from the tubes.
14. Submerged-tube, vertical-basket, and flash.

APPENDIX II

QUALIFICATIONS FOR ADVANCEMENT IN RATING

ENGINEMEN (EN)

Rating Code No. 3800

General Service Rating

Scope

Enginemen operate, maintain, and repair internal combustion engines; operate and maintain auxiliary engine room, refrigeration, and air conditioning equipment.

Emergency Service Ratings

ENGINEMEN D (Diesel Enginemen), Rating Code No. 3801--- **END**
Operate, maintain, and repair Diesel main propulsion and auxiliary engines and equipment.

ENGINEMEN G (Gasoline Enginemen), Rating Code No. 3802-- **ENG**
Operate, maintain, and repair gasoline main propulsion and auxiliary engines and equipment.

Navy Job Classifications and Codes

For specific Navy job classifications included within this rating and the applicable job codes, see Manual of Enlisted Navy Job Classifications, NavPers 15105 (Revised), codes EN-4300 to EN-4399.

Qualifications for Advancement in Rating

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
100 PRACTICAL FACTORS			
101 OPERATIONAL			
1. Start, operate, stand watch on, and secure refrigeration and air conditioning systems-----	3	3	3
2. Stand watch in steering engine room----------	3	3	-----

Qualifications for Advancement in Rating	Applicable Rates		
	EN	END	ENG
3. Use radiac instruments and perform monitoring operations on intake lines and evaporators	3	3	3
4. Engage and disengage jacking gear on Diesel engine	3	3	-----
5. Start, operate, and secure all hydraulic equipment	3	3	-----
6. Line up lubricating oil system	3	3	-----
7. Circulate lubricating oil through engine with stand-by lubricating oil pump	3	3	-----
8. Start, operate, and secure fire and flushing pump	3	3	3
9. Locate principal isolation valves of fire main system	3	3	3
10. Line up, start, operate, and secure lubricating- and fuel-oil purifiers and centrifuges	3	3	-----
11. See that oil is delivered to reduction gears and thrust bearings. Inspect for leaks	3	3	-----
12. Open drains to whistle and siren	3	3	-----
13. Cut in air to whistle and siren	3	3	-----
14. Take and log counter readings	3	3	-----
15. Start, operate, and secure a vapor compression distilling plant	3	3	-----
16. Detect high- or low-lubricating oil pressure	3	3	3
17. Start, operate, and secure Diesel generators	2	2	-----
18. Bleed fuel lines to injectors	2	2	-----
19. Heat lubricating oil in sump tank to 90° F and secure heating coils	2	2	-----
20. Make operational adjustments to clutches on small boat engines	2	2	2
21. Correct unusual or erratic operation of gasoline engines	1	-----	1
22. Correct unusual or erratic operation of Diesel engines	1	1	-----
23. Obtain permission from bridge, and turn main engines	1	1	-----
24. Time ignition systems on gasoline engines	1	-----	1
102 MAINTENANCE AND/OR REPAIR			
1. Clean strainers and change filters on Diesel engines	3	3	-----

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
2. Clean strainers and change filters on gasoline engines	3	-----	3
3. Lubricate all pumps and compressors (except refrigeration compressors)	3	3	3
4. Remove scale from evaporator tubes by cold shocking	3	3	-----
5. Spot and grind in valves	3	3	3
6. Renew bonnet gaskets in valves	3	3	3
7. Replace zinc plates in all salt water cooling systems	3	3	-----
8. Clean salt waterside of heat exchangers in main engine	3	3	-----
9. Change oil and lubricate Diesel generators	3	3	-----
10. Remove scale from evaporator tubes chemically	2	2	-----
11. Fit piston rings to cylinders of reciprocating pumps	2	2	-----
12. Test and renew suction and discharge valves on compressors	2	2	2
13. Use dial indicators, micrometers, bridge gages, depth gages, and inside-outside vernier calipers to take clearances on journals, bearings, liners, and pistons	2	2	2
14. Check for noncondensable gases and pump down refrigerant systems	2	2	2
15. Use halide torch to test for leaks on refrigeration or air conditioning equipment	2	2	2
16. Reface valve seats and discs	2	2	2
17. Lubricate refrigeration compressors	2	2	2
18. Repack high-pressure valves	2	2	-----
19. Spot in and replace bearings of centrifugal pumps	2	2	-----
20. Dehydrate, test, and recharge refrigeration systems	1	1	1
21. Replace oil seals on refrigeration compressors	1	1	1
22. Maintain and repair small boat clutches, transmissions, drive shafts (including alignment), and stern tube glands	1	1	1
23. Determine clearance of bearing in pumps, and check alignment of couplings	1	1	-----

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
24. Set all reducers and relief valves to required pressure	1	1	1
25. Take clearances and replace wearing rings on centrifugal pumps	1	1	-----
26. Check for alignment of centrifugal pump driving unit	1	1	-----
27. Test evaporator tubes hydrostatically for leaks	1	1	-----
28. Operate an engine lathe for cutting threads and tapers, and plain turning	1	1	1
29. Test fuel injection valves	1	1	-----
30. Take clearances on blower lobes	1	1	-----
31. Take clearances on blower gear train	1	1	-----
32. Maintain pumps and associated equipment in hydraulic systems	1	1	-----
33. Take reduction gear bearing clearances, thrust clearances, and Kingsbury thrust bearing clearances	1	1	-----
34. Check and adjust constant-speed and speed-limiting governors and overspeed trips	1	1	-----
35. Inspect propellers, shafts, sea valves, zincs, and strut and stern tube bearings when ship is in drydock	C	C	-----
36. Plug and replace condenser tubes	C	C	-----
103 ADMINISTRATIVE AND/OR CLERICAL			
1. Locate and use appropriate sections of BuShips *Manual*, manufacturers' instruction books, and handbooks to obtain necessary data when repairing machinery	1	1	1
2. Supervise and train personnel in operation, maintenance, and repair of:			
a. All engine room equipment	C	C	C
b. Refrigeration and air conditioning equipment	C	C	C
3. Take charge of an engine room watch on Diesel-driven ship under way	C	C	-----
4. Keep engine room records and prepare naval shipyard and tender work requests	C	C	C

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
5. Estimate time and material needed for repair of auxiliary and main propulsion machinery	C	C	C
6. Supervise and make out reports for full power, economy, dock, and post-repair trials	C	C	C
200 EXAMINATION SUBJECTS			
201 OPERATIONAL			
1. Safety precautions involved in performing the tasks appropriate to the applicable rates listed under 100 practical factors			
2. Causes and prevention of crankcase explosions	3	3	-----
3. First-aid procedures in cases of electrical shock, heat exhaustion, and exposure to refrigerants in liquid or gaseous states	3	3	3
4. Safety precautions to be observed when working on shipboard machinery, taking on fuel, and moving or lifting heavy objects	3	3	3
5. Safety precautions involved when refueling and starting gasoline-powered small boats	3	-----	3
6. Safety precautions required when testing injectors	3	3	-----
7. Principles and operation of the following:			
a. Four-stroke cycle engine	3	3	3
b. Two-stroke cycle engine	3	3	-----
c. Double acting engine	3	3	-----
d. Opposed piston engine	3	3	-----
e. Single acting engine	3	3	3
8. Meaning and significance of:			
a. Compression ignition principle	3	3	3
b. Diesel cycle	3	3	-----
c. Power stroke	3	3	3
d. Exhaust stroke	3	3	3
e. Scavenging	3	3	-----
f. Turbulence	3	3	3
g. Precombustion	3	3	-----
h. Supercharging	3	3	-----
i. Internal combustion engine	3	3	3
j. True Diesel engine	3	3	-----
k. Semi-Diesel engine	3	3	-----
l. Otto cycle	3	-----	3

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
9. Capacity and limitations of fire-fighting equipment driven by gasoline engines	3	-----	3
10. Capacity and limitations of fire-fighting equipment driven by Diesel engines	3	3	-----
11. Trace path of lubricating oil through a Deisel engine	3	3	-----
12. Trace path of lubricating oil through a gasoline engine	3	-----	3
13. Trace path of cooling water through an internal combustion engine (open system and closed system)	3	3	3
14. Principles of operation of ignition systems on gasoline engines	3	-----	3
15. Principles and use of compression, oil-control, and oil-scraper piston rings	3	3	3
16. Standards to be followed in determining hardness, alkalinity, and salinity of water	3	3	3
17. Purpose and principles of operation of:			
a. Reduction gears	3	3	3
b. Distilling plants	3	3	3
c. Three-stage air compressors	3	3	3
d. Lubricating oil purifiers	3	3	3
e. Exhaust silencers	3	3	3
f. Air coolers	3	3	-----
g. Reciprocating, gear, and centrifugal pumps	2	2	-----
h. Jacking gears	2	2	-----
i. Relief valves	2	2	2
j. Diesel generators	2	2	-----
k. Hydraulic couplings	2	2	-----
l. Air starting systems	2	2	-----
m. Principles and operation of electrical starting systems	2	2	2
18. Procedures involved in making the following tests on fuel and lubricating oil:			
a. Viscosity	2	2	2
b. Flash point	2	2	2
c. Fire point	2	2	2
d. Cetane	2	2	2
e. Water and sediment	2	2	2

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
19. Procedures to be followed when these symptoms appear on gasoline engines:			
a. Hunting	1	-----	1
b. Engine misses	1	-----	1
c. Engine fails to start	1	-----	1
d. Engine starts but will not run continuously	1	-----	1
e. Engine runs unevenly	1	-----	1
f. Engine will not turn over	1	-----	1
g. Engine stops suddenly when running	1	-----	1
h. Unusual noises in engine	1	-----	1
i. Engine runs with ignition switch off	1	-----	1
20. Procedures to be followed when these symptoms appear on Diesel engines:			
a. Hunting	1	1	-----
b. Failure to start	1	1	-----
c. Contamination of fuel oil, lubricating oil, and cooling water	1	1	-----
d. Engine will not turn over	1	1	-----
e. Low or high firing pressure	1	1	-----
f. Loss of lubricating oil pressure	1	1	-----
g. Low scavenging air receiver pressure	1	1	-----
h. High exhaust back pressure	1	1	-----
i. Excessive smoke	1	1	-----
j. High cylinder temperature	1	1	-----
k. Low cylinder temperature	1	1	-----
l. Excessive vibration	1	1	-----
21. Causes and prevention of:			
a. Excessive and undue piston wear	1	1	1
b. Cracked piston	1	1	1
c. Broken lands	1	1	1
d. Piston skirt seizure	1	1	1
e. Excessive ring groove clearances	1	1	1
f. Clogged oil holes	1	1	1
g. Worn piston pin bushing	1	1	1
h. Too high lubricating oil temperatures	1	1	1
i. Lubricating oil line leakages	1	1	1
j. Loose connecting rod bearings	1	1	1
k. Misaligned connecting rods	1	1	1
l. Out-of-round cylinder bore	1	1	1
m. Scored journals	1	1	1

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
21. Causes and prevention of—Continued			
n. Journal bearing failures	1	1	1
o. Damaged shaft or thrust bearings	1	1	1
22. Construction and operation of Freon-12 type of refrigerating units. Characteristics of refrigerants	1	1	1
23. Purpose and principles of operation of:			
a. Refrigeration expansion valves	1	1	1
b. Thrust bearings	1	1	1
c. Governors	1	1	1
d. Overspeed trips	1	1	1
24. Emergency procedures in starting Diesel engines	C	C	-----
25. Principles of operation of the common rail, distributor (Bosch), and individual unit injector systems	C	C	-----
202 MAINTENANCE AND/OR REPAIR			
1. Purpose and procedures for cold shocking evaporators	3	3	-----
2. Procedures to be followed when:			
a. Changing and cleaning fuel and lubricating oil strainers and filters	3	3	3
b. Lubricating Diesel electric generating equipment	3	3	-----
c. Repacking stuffing boxes on centrifugal pumps	3	3	3
d. Replacing zinc plates in main and auxiliary heat exchangers	3	3	3
e. Removing scale from evaporator tubes	2	2	-----
f. Testing and renewing suction and discharge valves on compressors	2	2	2
g. Spotting in and replacing bearings of centrifugal pumps	2	2	2
h. Renewing cylinder liners	2	2	2
i. Renewing pistons and rings in internal combustion engines	2	2	2
3. Methods of taking oil clearances in bearings	2	2	2
4. Methods of testing evaporators and condensers for salt water leaks	2	2	2

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
5. Principles of operation of the following gasoline engine units:			
a. Distributors	2	-----	2
b. Flywheels	2	-----	2
c. Starting motors	2	-----	2
d. Fuel pumps	2	---	2
e. Carburetors	2	-----	2
f. Spark plugs	2	-----	2
g. Generators	2	-----	2
h. Ignition coils	2	-----	2
i. Batteries	2	-----	2
j. Lubricating oil pumps	2	-----	2
k. Water pumps	2	-----	2
l. Transmissions	2	-----	2
6. Methods of grinding, refacing, and setting intake and exhaust valves	2	2	2
7. Lubricant requirements and precautions when handling dehydrated oils for refrigerant systems	1	1	1
8. Procedures to be followed when:			
a. Repairing centrifugal pumps	1	1	-----
b. Taking clearances and renewing parts on centrifugal pumps	1	1	-----
c. Checking alignment of centrifugal pump driving unit	1	1	-----
d. Dehydrating, testing, and recharging refrigeration systems	1	1	1
e. Disassembling, cleaning, replacing, repairing, and assembling fuel oil injection valves	1	1	-----
f. Replacing oil seals on refrigeration compressors	1	1	1
g. Methods of testing and adjusting fuel oil injection valves	1	1	-----
9. Methods of testing refrigerating systems, including compressors, for proper operation	1	1	1
10. Procedures to be followed when pulling:			
a. Liners	1	1	1
b. Pistons	1	1	1
c. Cylinder heads	1	1	1
d. Wrist pins	1	1	1
e. Piston rings	1	1	1
f. Bearings	1	1	1

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
11. Factors governing main propulsion plant efficiency; causes of poor performance, and appropriate remedies	C	C	C
12. Causes of inefficient operation of refrigerating systems, and corrective procedures	C	C	C
13. Procedures for checking and adjusting constant-speed and speed-limiting governors and overspeed trips	C	C	-----
14. Methods of taking main engine and reduction gear bearing clearances and thrust clearances	C	C	-----
15. Purpose, study, and interpretation of Diesel engine indicator cards	C	C	
203 ADMINISTRATIVE AND/OR CLERICAL			
1. Duties and responsibilities of the engineer officer of the watch	C	C	C
2. Performance and casualty reports required by BuShips and Chief of Naval Operations, and all records to be kept by the engine room	C	C	C
3. Selection, procurement, and use of packings, greases, oils, polishes, cleaning materials, spare parts, and other engine room supplies	C	C	C
4. Use of allowance lists and procedures for maintaining inventories and obtaining replacements	C	C	C
5. Application of damage control principles	C	C	C
6. Knowledge of administrative, material, and operational readiness inspections	C	C	C

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